ECHNOLOGY DEPT.

THE JOURNAL OF

THE INSTITUTION OF PRODUCTION ENGINEERS

Vol. 30, No. 4, April 1951

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Extract

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FOR REGULARITY OF FINISH

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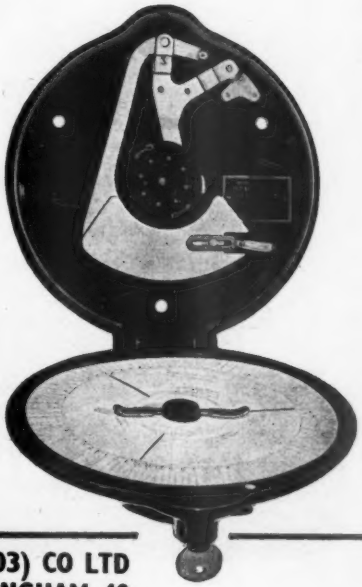
Extract from letter received from Servis Recorders, Gloucester.



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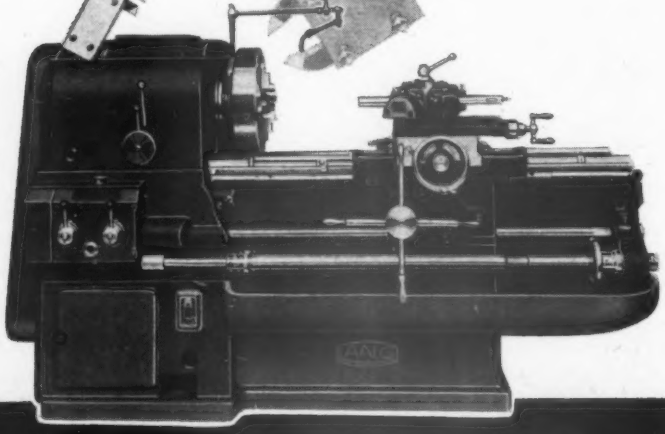

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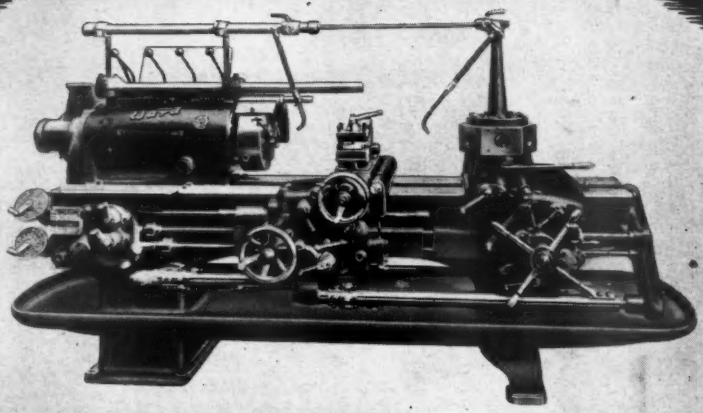

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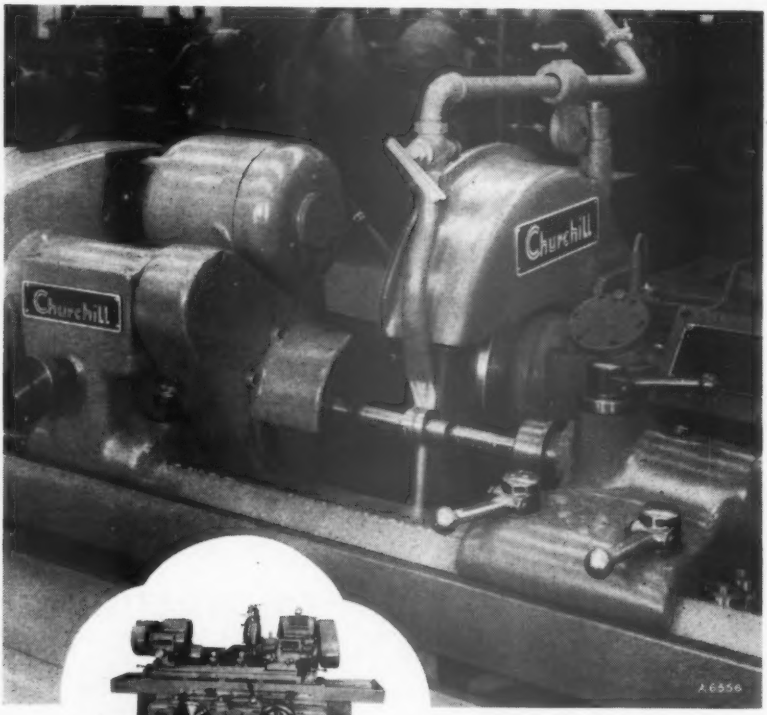

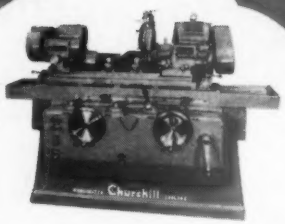

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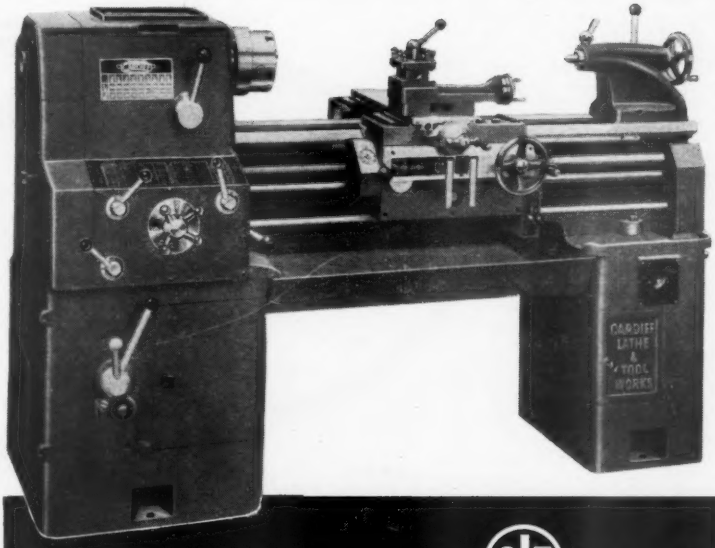

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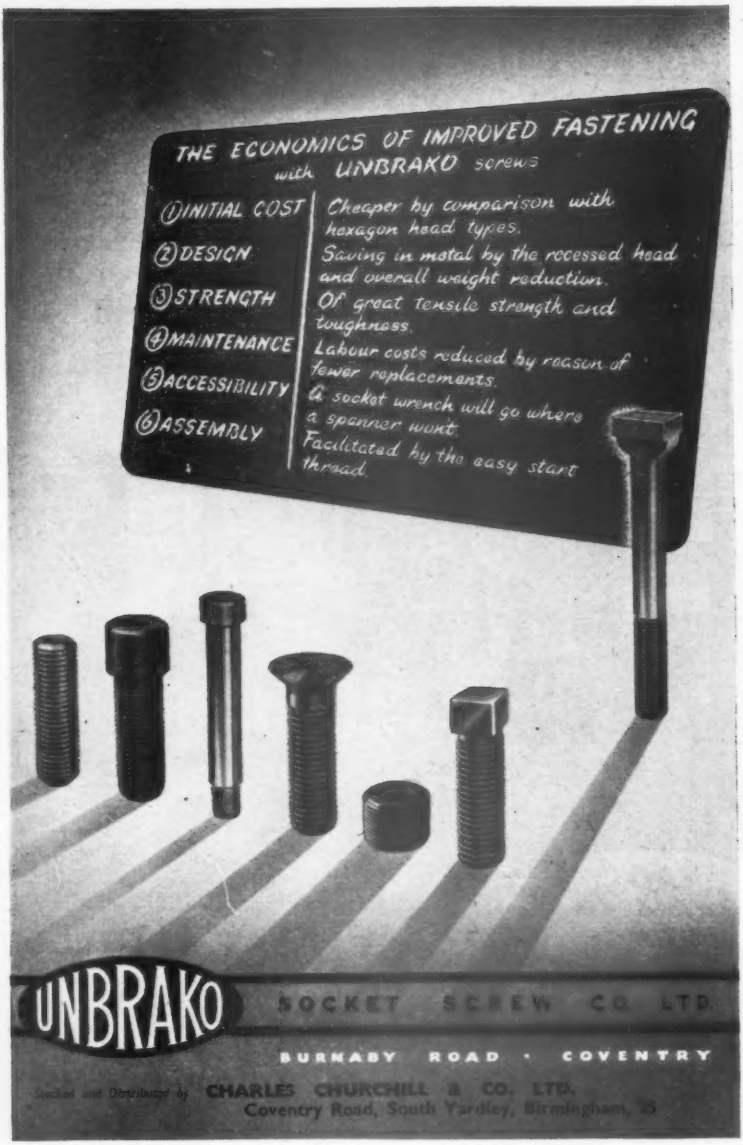
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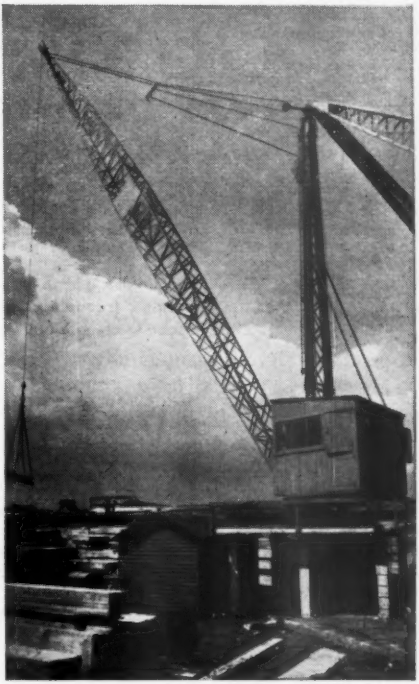

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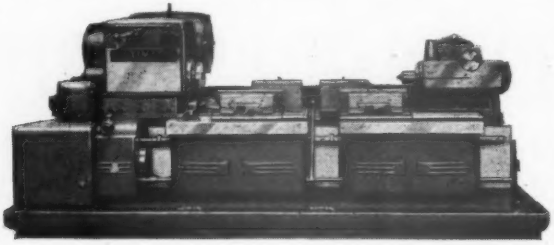

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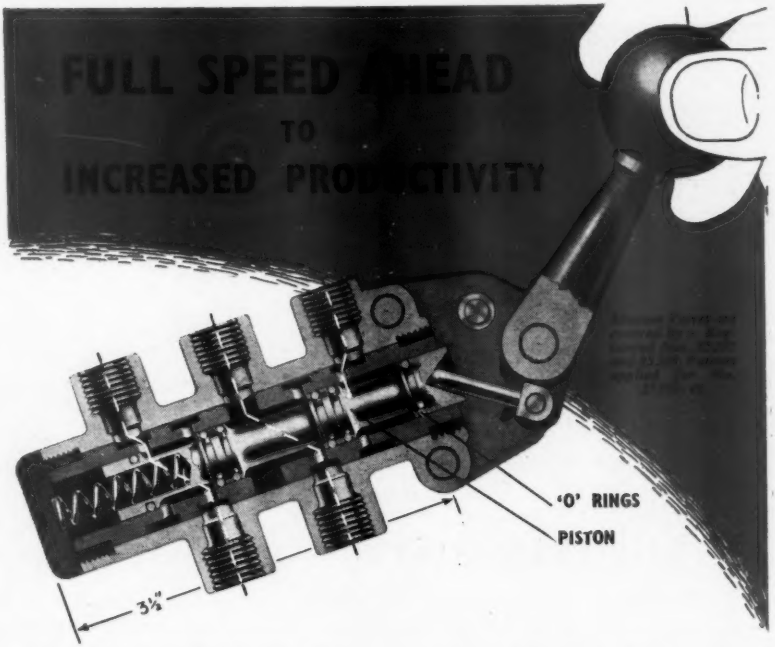

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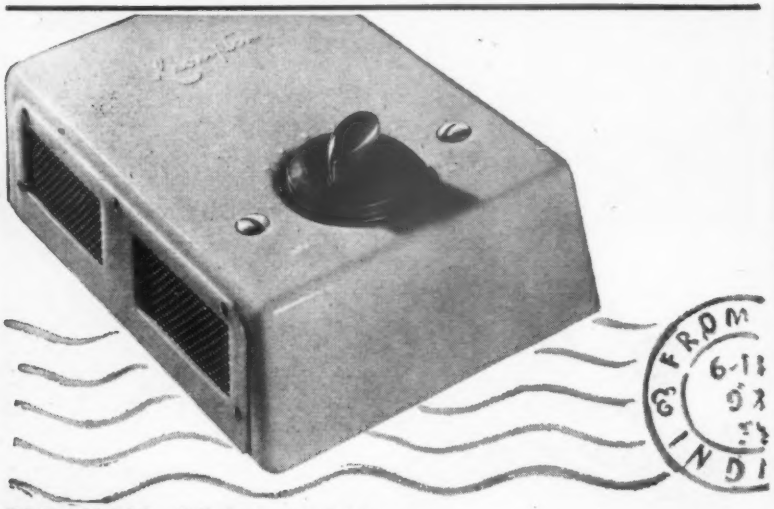

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THE JOURNAL OF

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Vol. 30, No. 4, April 1951

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INSTITUTION NOTES

April, 1951

CHAIRMAN OF COUNCIL'S NEW APPOINTMENT

MANY members will have read or heard on the radio that our Chairman of Council, Mr. Walter C. Puckey, has been invited by Mr. Strauss, Minister of Supply, to assist in the rearmament programme.

Mr. Puckey has, with the consent of his Board, been lent to the Ministry for an indefinite period and will, in his capacity of Deputy Controller of Supplies (Air) be particularly responsible for the new R.A.F. production programmes.

COUNCIL ELECTIONS, 1951/52

(a) In addition to Officers and Section representatives, Council includes twelve Elected Members (i.e., ten Members and two Associate Members). In accordance with Article of Association 33(c), six of these twelve members (i.e., five Members and one Associate Member), shall retire each year, but they may seek re-election.

(b) In accordance with Article 35, nominations are now invited to fill six vacancies for elected members to serve on Council for 1951/52 (i.e., five Members and one Associate Member).

(c) Candidates for election must be nominated in writing by three Members or Associate Members of the Institution, nominations to reach Head Office not later than 23rd April, 1951.

(d) In addition to nominations as in (c), each Section Committee may nominate one candidate.

N.B.—Before nominating candidates for election, their prior consent should be obtained.

The retiring Members of Council, who are willing to stand for re-election are as follows.

	Attendances at Council	
	Possible	*Actual*
Mr. E. D. Broome, A.M.I.Prod.E.	8	4
Mr. R. M. Buckle, M.I.Prod.E.	8	5
Mr. R. C. Fenton, M.I.Prod.E.	8	7
Mr. H. G. Gregory, M.I.Prod.E.	8	5
Prof. T. U. Matthew, M.I.Prod.E.	8	2

MEETING OF COUNCIL The next meeting of Council will be held on 26th April, 1951, at 11 a.m., at 36, Portman Square, London, W.1.

AMERICAN SOCIETY OF TOOL ENGINEERS The President of the Institution has been in communication with Mr. H. L. Tigges, President of the American Society of Tool Engineers, and feels that members will be interested in the following paragraphs from a recent letter he has received :

" I note that you and your members from time to time have " occasion to visit our country, and I hope that in the event of " these visits, time will allow contacting our Society, and visiting " us in our main Headquarters Office in Detroit.

" With our common interests, in the event of visits of your " members to our country, I feel it would be very constructive if " we could arrange to get together to discuss mutual problems."

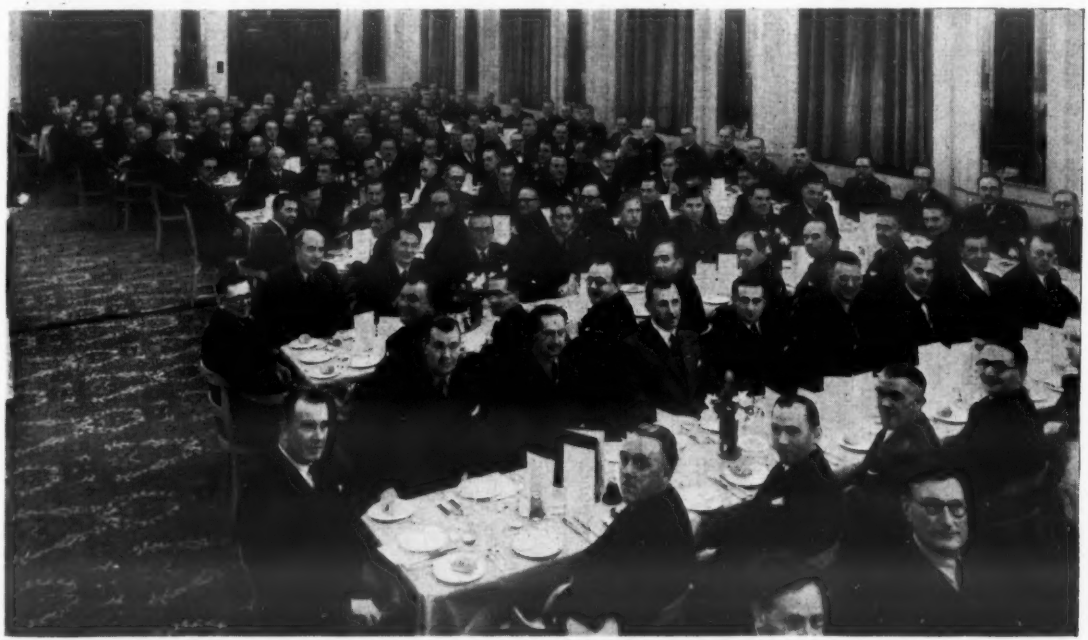
General Appleyard feels sure that any members visiting the United States will receive a warm welcome and much assistance from Mr. Tigges.

MOTION AND TIME STUDY Professor Marvin E. Mundel, Head of the Department of Industrial Engineering at Purdue University, Lafayette, Indiana, is visiting the Department of Engineering Production at the University of Birmingham under the Fulbright scheme during the next six months, and he is taking part in lectures and discussions during this period on the subject of Motion and Time Study and their Application in Industry.

He has arranged to give a series of lectures to which members of the Institution are invited. The first of these will be held on 25th April 1951, and will be a joint meeting of engineering institutions arranged by the Birmingham Section of the Institution of Production Engineers, on " Recent American Developments in Industrial Engineering Practice."

This will be followed by a series of four lectures at the University of Birmingham, Edgbaston, on topics selected to show the application of new approaches to the problem of increasing productivity and reducing industrial costs. The titles of the lectures are :—

1. Possibility Guides—the starting point for productivity studies.
2. Process Analysis—an operating tool in productivity studies : (with specific reference to office procedures).
3. Uses of motion picture techniques in productivity studies.
4. Objective Ratings—a new time study technique.



The London Section Dinner, held on 1st February, 1951, with Mr. William Core, Section President, in the Chair.

These lectures will be held on the afternoons of Fridays the 4th, 11th, 18th, 25th May, 1951, at 4-00 p.m., and Institution members wishing to attend should apply to the Secretary, Department of Engineering Production, The University, Edgbaston, Birmingham, for admission tickets.

LONDON SECTION DINNER The first social function to be held by the London Section since the war—a dinner on February 1st last—was a decided success in every way.

Mr. William Core, Section President, was in the Chair, and Major-General K. C. Appleyard, President of the Institution, was the principal guest, the other official guests being Mr. Walter C. Puckey, Chairman of Council ; Mr. Harold Burke, Vice-Chairman of Council and President of the Birmingham Section ; the Secretary and the Education Officer of the Institution, Mr. W. F. S. Woodford and Mr. T. B. Worth ; and Mr. S. Caselton and Mr. G. E. Knight, senior members of the Headquarters staff.

Speeches were interesting and entertaining, but brief. Mr. J. B. S. Gabriel, President of the Machine Tool Trades Association, proposed the toast of the Institution to which Major-General Appleyard responded. Mr. Burke proposed the toast of the London Section and Mr. Core replied. The toast of the Guests was proposed by Mr. A. L. Stuchbery and Mr. Puckey replied on their behalf.

The evening concluded with an excellent entertainment blending humour with straight singing.

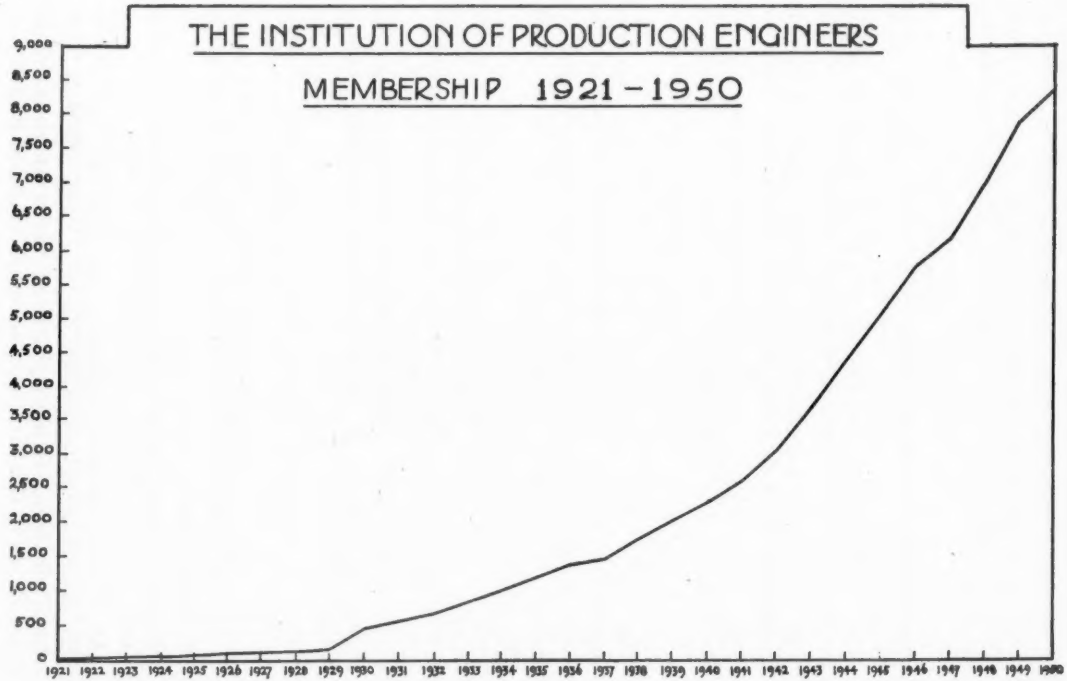
GROWTH OF MEMBERSHIP In response to enquiries from members following the article on Membership Qualifications in the March issue of the *Journal*, the chart on the following page has been prepared showing the growth of the Institution's membership from its foundation in 1921 to 1950.

NEWS OF MEMBERS

Mr. J. McBride, Associate Member, has been transferred to Hoover (Electric Motors) Ltd., Cambuslang, as Tool Investigator in the Production Engineering Department.

Mr. J. Bamford, Associate Member, has rejoined Vauxhall Motors Ltd., Luton, as Planning Engineer.

Mr. F. E. Bates, Associate Member, is giving a series of lectures at Croydon Polytechnic, commencing on 9th April, 1951. The subject will be " The Manufacture, Design and Application of Tungsten Carbide Cutting Tools."


THE INSTITUTION OF PRODUCTION ENGINEERS
MEMBERSHIP 1921 – 1950
9,000
8,500
8,000
7,500
7,000
6,500
6,000
5,500
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
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1921 1922 1923 1924 1925 1926 1927 1928 1929 1930 1931 1932 1933 1934 1935 1936 1937 1938 1939 1940 1941 1942 1943 1944 1945 1946 1947 1948 1949 1950

Mr. A. Beeching, Member, has been appointed Superintendent of the Royal Ordnance Factory at Glascoed, Mon.

Mr. A. H. Blackwell, Member, Works Manager of David Brown Tractors (Engineering) Ltd., Huddersfield, has been appointed to the Board of Directors.

Mr. Shiri S. N. Chatterjee, Associate Member, has been appointed Works Manager of the Rifle Factory, Ishapore, West Bengal.

Mr. W. R. Childs, Associate Member, is now Group Production Engineer with Parkinson & Cowan, Ltd., London.

Mr. R. N. Dass, Associate Member, has been appointed Assistant Works Manager of the Ordnance Factory, Dehra Dun, India.

Mr. D. L. Davies, Intermediate Associate Member, is now Production Manager with Signode Ltd., Swansea.

Mr. J. L. Elliott, Associate Member, has been appointed Chief Engineer with Philips Blackburn Works, Blackburn, Lancs.

Mr. G. F. P. Fox, Associate Member, has been appointed Supplies Development Engineer, with Rolls Royce Co. Ltd., Derby.

Mr. A. W. Hallpike, Member, has been appointed General Manager of the Motor Construction Works of the Bristol Tramways & Carriage Co. Ltd.

Mr. F. H. Perkins, Member, and Mr. W. J. Izzard, Associate Member, are members of the A.A.C.P. Foremanship Team which is at present visiting the U.S. to survey American facilities for foremanship training and selection.

Mr. E. J. Parker, Associate Member, has been appointed Mechanical Engineer at the Public Works Department, Lusaka, Northern Rhodesia.

Mr. J. R. Pettigrew, Associate Member, is now Works Manager of Alexander Shanks & Sons, Ltd., Dens Iron Works, Arbroath.

Mr. A. Webster, Associate Member, has been appointed Assistant to the Works Manager of David Brown Tractors (Engineering) Ltd., Huddersfield.

Mr. A. A. Young, Associate Member, is now Resident Engineer (Traction) for the English Electric Co. Ltd., in Cairo.

Mr. W. H. Crawshaw, Graduate, is now Planning Engineer with David Brown Tractors (Engineering) Ltd., Huddersfield.

Mr. D. Eastwood, Graduate, has joined the Renold and Coventry Chain Co. Ltd., Didsbury, Manchester, as Technical Engineer.

Mr. Norman Holmes, Graduate, is now Production Methods Engineer (Assembly Dept.) with F. Perkins Ltd., Peterborough.

OBITUARY The Institution deeply regrets to announce the death of Major James Erskine, T.D., M.A., B.Sc., Associate, a member of the Edinburgh Section Committee.

BRITISH STANDARDS The following Standards have recently been issued and are available, post free, from the British Standards Institution, 28, Victoria Street, Westminster, London, S.W.1, at the prices indicated :

235 : 1951 Gears for Traction, 4/–.

814 : 1950 Mild Steel Drums (Light Duty, Fixed Ends), 2/–. (I.Prod.E. representative on appropriate committee : Mr. L. P. Coombes).

959 : 1950 Internal Micrometers (including Stick Micrometers), 2/–. (I.Prod.E. representative on appropriate committee : Mr. J. E. Baty).

1133 : 1950 Adhesive Closing and Sealing Tapes, 3/–. (I.Prod.E. representative on appropriate committee : Mr. L. P. Coombes).

1134 : 1950 Assessment of Surface Texture (Centre-Line-Average Height Method), 6/–. (I.Prod.E. representative on appropriate committee : Mr. J. E. Baty).

1262 : Part 2 : 1950 Sizes of Tins for Paint and Varnishes, 2/–. (I.Prod.E. representative on appropriate committee : Mr. L. P. Coombes).

1663 : 1950 Higher Tensile Steel Chain (electrically welded), 2/6.

1686 : 1950 Long-Period, High-Sensitivity Tensile Creep Testing, 2/–.

1687 : 1950 Medium-Sensitivity Tensile Creep Testing, 2/–.

1688 : 1950 Determination of Time to Rupture Under Stress, 2/–.

1692 : 1950 Gin Blocks, 2/–.

1700 : 1950 Typical Ships' Derrick Rigs, 7/6.

1701 : 1950 Air Filters for Internal Combustion Engines and Compressors, 4/–.

1702 : 1950 Mild Steel Drums (Heavy Duty, Fixed Ends), 2/–. (I.Prod.E. representative on appropriate committee : Mr. L. P. Coombes).

BOOKS RECEIVED " Modern Management for Bakers and Confectioners (Book II, Flour Confectionery) " by E. Victor Adamson and H. E. Turner. *Trade Technical Services, Ltd., London*, price 10/6 post free.

STAFF APPOINTMENTS

Following the appointment of Mr. W. F. S. Woodford as Secretary, two further appointments have been made.

Mr. S. Caselton, who first joined the Institution staff in 1936, is now Assistant Secretary (Administration), and Mr. G. E. Knight, who joined the staff in 1946, is now Assistant Secretary (Education and Membership).

LONDON SECTION At the meeting of the London Section which will take place on 19th April at the Royal Empire Society, London (Craven Street entrance), at 7-00 p.m., Mr. K. A. Zandstra, A.M.I.E.E., will lecture on "High Frequency Heating in Production."

THE LIBRARY The Library will be open between 10 a.m. and 5.30 p.m. on Mondays, Tuesdays, Thursdays and Fridays; between 10 a.m. and 8 p.m. on Wednesdays; and between 10 a.m. and 1 p.m. on the first Saturday of every month.

JOURNAL BINDERS Members are reminded that binding cases for the Journal are obtainable from Head Office, price 7/6 each post free. The cases, each of which will hold 12 issues of the Journal, are made of stiff board covered with imitation leather cloth, with gilt lettering on the spine.

CHANGE OF ADDRESS It would be of great assistance to Head Office if members would ensure that the business addresses contained in their records were up-to-date, and would notify Head Office as soon as possible of any change of appointment.

RESEARCH PUBLICATIONS A number of copies of the following Research publications are still available to members, at the prices stated :

Report on Surface Finish, by Dr. G. Schlesinger	15/6
Machine Tool Research & Development	10/6
Practical Drilling Tests	21/-
Test Charts for Machine Tools, Parts 3 and 4	5/6 each

These publications may be obtained from the Production Engineering Research Association, "Staveley Lodge", Melton Mowbray, Leics.

ISSUE OF JOURNAL Owing to the fact that output has to be adjusted to meet requirements, and in order to avoid carrying heavy stocks, it has been decided that the Journal will only be issued to new Members from the date they join the Institution.

IMPORTANT In order that the Journal may be despatched on time, it is essential that copy should reach the Head Office of the Institution not later than 40 days prior to the date of issue, which is the first of each month.

SECTION MEETINGS

The following meetings have been arranged to take place in May, 1951. Where full details are not given, these have not been received at the time of going to press.

MAY

2nd **Nottingham Section.** There will be a discussion among five members of productivity teams recently returned from the United States of America, at the Victoria Station Hotel, Milton Street, Nottingham, at 7-00 p.m.

8th **Birmingham Graduate Section.** A lecture on "Fundamental Machining Problems associated with the Production of Gas Turbine Components" by P. Spear, Esq., B.Eng., Grad.I.Prod.E., at the James Watt Memorial Institute, Great Charles Street, Birmingham, 3, at 7-00 p.m.

10th **Southern Section.** A lecture on "Planning for Production Incorporating Cost Control" will be given by C. W. Higgins, Esq., A.C.I.S., A.C.C.A., A.M.I.I.A., at the Polygon Hotel, Southampton, at 7-00 p.m.

22nd **Wolverhampton Graduate Section.** A lecture on "Metrology" will be given by G. H. Rutland, Esq., M.B.E., A.K.C., M.I.Mech.E., M.I.Prod.E., at the Wolverhampton & Staffs Technical College.

30th **Shrewsbury Sub-Section.** A lecture on "Commercial Possibilities of the Lost Wax Process" will be given by A. Short, Esq., A.M.I. Prod.E., M.I.B.F., at the Technical College, Shrewsbury, at 7-30 p.m.

STEEL—THE ENGINEER'S CLAY

by F. WESTALL, M.A., A.M.I.Mech.E., A.M I.Prod.E.

Presented to the Preston Section of the Institution, 8th November, 1950

I TRUST the title of my talk is no misnomer. I intend to speak on steel, for steel is to the engineer what clay is to the potter.

I must make it clear that I am not a metallurgist, and I am an engineer. Like most engineers my education in metallurgy was elemental and cursory at the best. Considering the wide syllabus it could be little more. The necessity of making the best use of the materials at my disposal, along with perhaps a little personal interest, has forced me to learn more of this subject, with special focus on steel.

My appreciation of the matter I have attempted to reduce to a simplified form, a basic framework of logical sequence with a mechanical bias. This system is by no means comprehensive and frequently glosses over the more abstruse parts, but I find it forms a useful background, and though certainly not dispensing with the necessity of advice by metallurgical specialists, enables this to be taken with better understanding and used to greater advantage.

It is the picture of metallurgy as applying to steel that I intend to put before you tonight.

MOLECULAR COMPOSITION Metal can be considered as being composed primarily of molecules, either arranged in regular pattern which we refer to as the crystalline state, or irregularly disposed, this being the amorphous condition.

AMORPHOUS SUBSTANCES Examples of amorphous substances are liquids, glass and pitch. Their properties range between high strength with excessive brittleness and low strength with ductility.

These properties depend considerably on the rate of loading, the greater this rate the lower the ductility. Amorphous materials are subject to creep, the degree of course being dependent on the substance concerned. It is this property which must be remembered when creep in metals is under consideration.

MOLECULAR ARRANGEMENT IN SINGLE CRYSTALS A single crystal of pure metal has negligible strength. Fig. 1 shows the molecular arrangement in such a crystal. Distortion of this molecular system occurs by one layer of molecules sliding over another (Fig. 2). This means that breakdown in one crystal is due to shear ; note the molecules being pulled apart against their mutual attraction.

Taking an analogy of fluid flow we can expect this state of affairs. The methodical arrangement of molecules implies a regular conformation of forces holding the molecules in their relative positions. From this it may be inferred that there will be some definite relation between displacement and applied load ; note the stress-strain relation of Hooke's law. Up to a certain magnitude of applied force the internal forces resisting molecule displacement will increase, holding the molecules in equilibrium against the applied force. On the removal of the applied force these internal forces will pull back the molecules to their nominal positions. Beyond this limiting imposed force the molecules will be forced out of the range of attraction of " elastic " restraining forces. The molecules in this plane of failure will loose their orderly arrangement and a lamina of an amorphous nature will result. To all intents and purposes the crystal has been broken into a number of

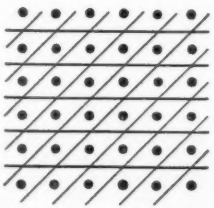

Fig. 1.—Regular molecular pattern in single crystal of homogeneous metal.

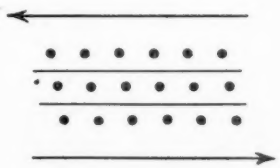

Fig. 2.—Uniform molecular displacement under light load.

smaller crystals, the break planes being parallel to the direction of the applied force.

GRAIN REFINEMENT

Fig. 3 shows the boundary between three crystals. Since the crystal axes take random directions it is most unlikely that the gliding plane of one will be a continuation of the gliding plane of its neighbour. This change of direction of gliding plane creates an added resistance to the applied force. The greater the number of gliding plane breaks, the greater the strength. This can be considered the first basic method of improving the mechanical strength, i.e. that of increasing the number of crystals or grain refinement. At the boundary between adjacent crystals where the pattern of one changes to that of another, there must be a region of molecules disposed in a disorderly fashion. This region is, therefore, of an amorphous nature and is known as

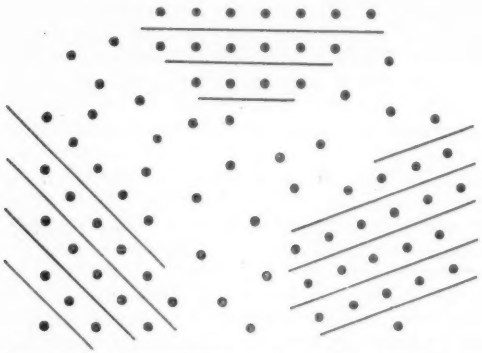

Fig. 3.—Molecular arrangement at boundary of three crystals.

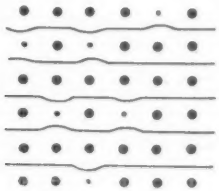

Fig. 4.—Pegging of crystal lattice by single element molecules.

boundary cement. It appears logical to assume that creep takes place in this area.

PEGGING BY ELEMENTAL MOLECULES An element is in solid solution in another when molecules of the first take the place of molecules of the parent element in the crystal lattice (Fig. 4). These foreign molecules obviously distort the gliding planes thereby increasing the resistance to slip. They are said to peg the crystal lattice. This is the second of the basic methods greatly affecting the mechanical properties.

PEGGING BY COMPOUND MOLECULES The third method is actually a sub-section of the second, but because of its profound effect must be considered on its own. Compound molecules are many times larger than those of simple elements and have, therefore, a tremendous effect when in solid solution (Fig. 5). Sometimes, because of their extreme hardness, in crystals of their own they

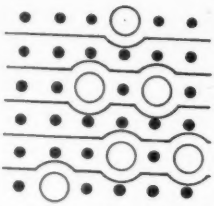

Fig. 5.—Pegging of crystal lattice by compound molecules.

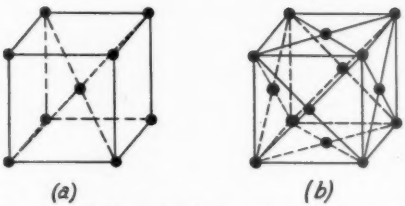

Fig. 6.—Cubic molecule system in Alpha and Gamma iron crystals.

exert a powerful influence. By causing compound formation, then, the mechanical properties can be enormously affected, especially so when the compound is in solid solution.

The mechanical properties of metals can in most part be ascribed to these three systems of resisting distortion in the crystal arrangement. Other factors play a part, but by no means to the same extent.

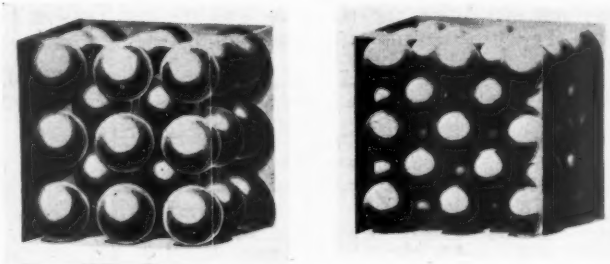

Fig. 7.—Pictorial view of cubic molecule system in Alpha and Gamma Iron crystals—Bain P. 7.

CARBON SOLUBILITY, ALPHA AND GAMMA IRON Iron exists in two isometric crystalline forms; alpha which is cubic and body centred, gamma being cubic and face centred (Figs. 6 and 7). Gamma iron, austenite, will hold in solution relatively large quantities of carbon, whereas alpha, ferrite, can contain little more than 0·01% at room temperatures. This is indeed fortunate, for it is this property which is responsible for the powerful mechanical properties of steel. Fig. 8 shows carbon solubility against temperature.

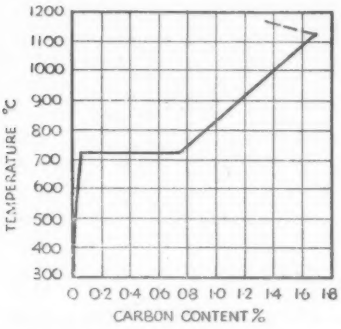

Fig. 8.—Carbon solubility in iron.

EQUILIBRIUM DIAGRAM The equilibrium diagram, Fig. 9, gives the state of carbon steel at different temperatures under equilibrium conditions. At approximately 723° C. iron changes its allotropic state from austenite to ferrite. This is coupled with a reorganisation of the crystal formation, carbon is thrown out of solution and combines with the iron forming iron carbide (Fe_3C), better known as cementite.

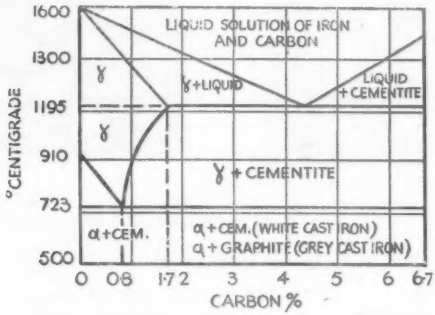

Fig. 9.—Iron carbon equilibrium diagram.

CRYSTALLISATION ON COOLING On cooling a carbon steel of almost eutectic composition, at the change point cementite and ferrite crystals are formed simultaneously and are arranged in a lamella manner, comprising alternative plates of cementite and ferrite. These laminae are contorted, giving rise to no plane of

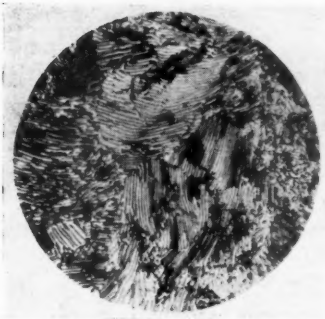

Fig. 10.—Micrograph of pearlite—Bain P. 31.

weakness, this state being known as pearlite. For pro-eutectoid steels of carbon content much removed from the eutectic, either ferrite or cementite first crystallises out until the remaining solution is of eutectic composition which transforms *en bloc* to pearlite. The microstructure of these steels consists of pearlite laminae in a matrix of either ferrite or cementite. Fig. 10 gives a typical microscopic appearance of pearlite.

	Approx. Cooling Rate : 760°C. To Transformation	Temp. of Transformation	Brinell Hardness Number
0.75%C	3° Per Minute	708°C.	210
	100° Per Minute	671°C.	315
	970° Per Minute	600°C.	415
1.0%C	2° Per Minute	705°C.	217
	50° Per Minute	682°C.	262
	220° Per Minute	673°C.	302

Fig. 11.—Effect of cooling rate on pearlitic hardness.

UNDERCOOLING AND GRAIN REFINEMENT

The decomposition of solid solution austenite is not begun instantly when the temperature is lowered below the equilibrium change point. There is a reluctance which is constant for any particular steel, and the degree of undercooling for the transformation to take place is necessarily dependent on the rate of cooling. The effect of cooling rate on hardness is shown in Fig. 11, which also gives the approximate transformation tempera-

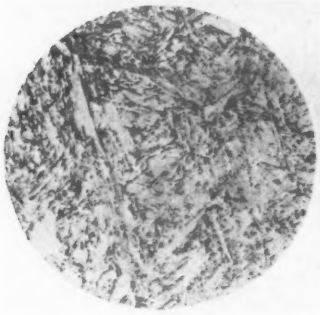

Fig. 12.—Microscopic appearance of martensite in eutectoid steel—Bain P. 34.

ture. In this case increased hardness can only come from grain refinement, which must, therefore, be greatly affected by the cooling rate.

SPHEROIDISED PEARLITE With certain steels, low in alloy content, especially when they are fine grained, at very low rates of cooling pearlite is not formed ; instead the carbide crystals coagulate in a spheroidised form.

Softening of Quenched Carbon Steels.

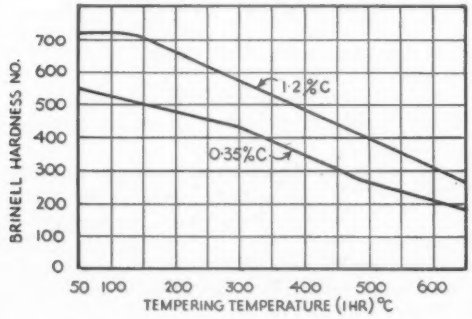

Fig. 13.—Tempering curves for 0·35% C and 1·2% C steels.

MARTENSITE With increasing rate of cooling, the transformation temperature is progressively lowered, the grain of the crystals becoming finer until a stage is reached when the carbide molecules are inhibited from clustering together and forming crystals. Instead they exist individually, still in the austenite crystal structure, the iron, of course, having reverted from austenite to ferrite. This, then, is a state in which the crystal lattice is pegged with compound molecules. It is known as martensite, and is steel in its hardest form. Fig. 12 is a photo-micrograph of martensite showing the needle-like structure.

TEMPERING Martensite, being of maximum strength, is deficient in other mechanical properties. Furthermore, because of the extreme rate of cooling internal stresses are set up, and these,

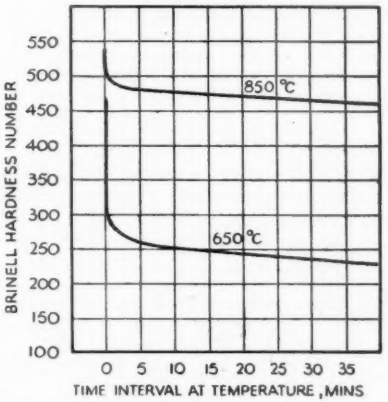

Fig. 14. Influence of time-interval on tempering 0·35% quenched steel.

in addition, impair the toughness. At elevated temperatures a certain migration of carbon atoms takes place. This process, commonly known as tempering, enables the molecular carbide structure in martensite to be broken down and agglomerations of carbides to be formed. This gives reduced hardness, but increased ductility and toughness, the toughness probably being dependent more on the release of internal strain than on the micro-structure rearrangement. The degree of tempering is mainly dependent on temperature as indicated in Fig. 13, showing the hardness of two carbon steels when held for one hour at various temperatures. Figs. 14 and 15 show the minor effect of time on this diffusion, the biggest drop in hardness taking place in the first few seconds. This

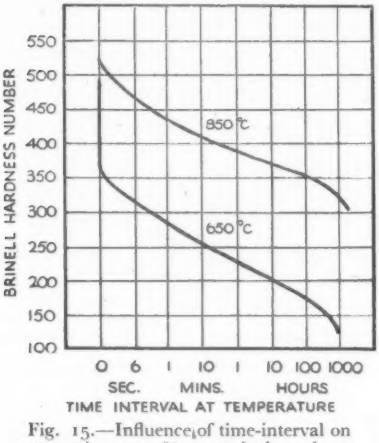

Fig. 15.—Influence of time-interval on tempering 0·35% quenched steel on logarithmic scale.

tempering of quenched steel gives properties superior to those of similar air cooled steel at the same degree of hardness. Fig. 16 shows the relative mechanical properties of a 0·84% carbon steel, on a hardness base, in one case air-cooled, and in the other hardened and tempered.

UNIFORMITY OF STRUCTURE AND CARBON CONTENT The resulting mechanical properties are greatly affected by uniformity of structure. Of special importance here is the distribution of carbon in the austenite crystals. This is accelerated by increase in solutioning

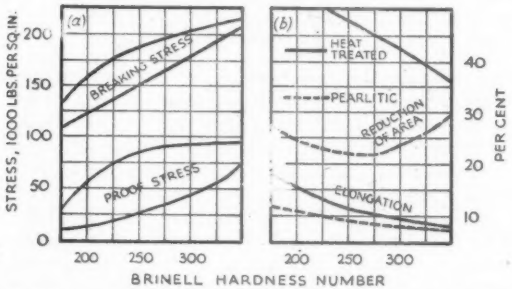

Fig. 16.—Relative mechanical properties of 0·84% C steel, (*a*) quenched and tempered, (*b*) air cooled. Proof sterss, breaking stress, elongation, reduction of area.

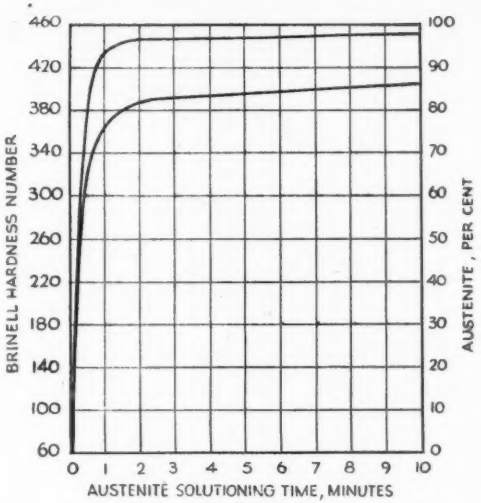

Fig. 17.—Increase in martensitic hardness by lengthening solution heating period, i.e., improving carbon distribution.

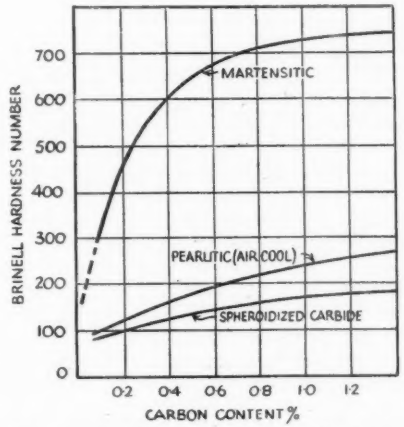

Fig. 18.—Influence of carbon on hardness. Martensite ; pearlite ; spheroidised pearlite.

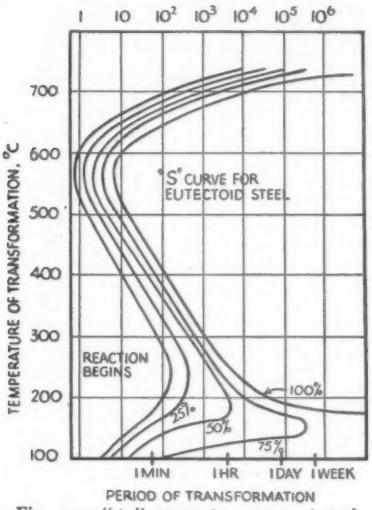

Fig. 19.—" S " curves for eutectoid steel.

temperature. Fig. 17 shows how martensitic hardness varies with solution heating period, the steel in question being 0·2% carbon, heated to 845° C. The carbon content, of course, greatly influences hardness, as is clearly shown in Fig. 18.

" S " CURVES AND BAINITE The simple equilibrium diagram is of no great assistance because of the predominant effect of the rate of cooling. Curves have been plotted to show for various steels when the transformation from austenite begins and when it ends. One such curve, known as an " S " curve, is shown in Fig. 19. This curve clearly shows that for martensite to form, the rate of cooling has to be so great as to take the steel past the top inward bulge. Martensite formation occurs when the curve is crossed at approximately 100° C. It will be seen also that it is possible to produce a further family of structures by rapid cooling to range roughly between 550° and 150° C. and holding at this temperature for varying times. This gives a formation of a microscopic acicular structure often containing residual austenite. These steels have interesting mechanical properties and in many cases for the same hardness are tougher than tempered martensite.

HARDENABILITY The rate of cooling is greatly dependent on the mass of steel concerned, that on the outside cooling far faster than that inside. With all but small sections of unalloyed

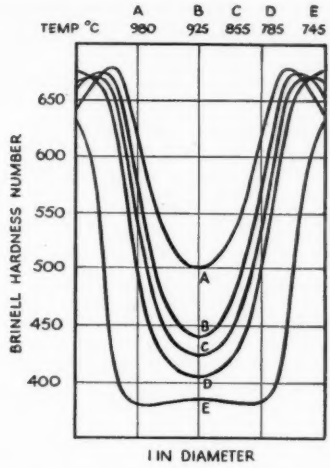

Fig. 20.—Effect of austenite grain size, as controlled by solutioning temperature, on hardenability. 0·74% C ; 0·41% Mn; 0·14% S.
Solutioning temperatures—980° C. ; 925° C. ; 855° C. ; 785° C. ; 745° C.

carbon steels, it is impossible to produce a uniform martensite throughout. Except for the outer layers, the relatively slow rate of cooling at the centre gives rise to the normal pearlitic formation. Austenite grain size is a deciding factor in hardenability, that is the depth to which martensite will be formed at a specific rate of cooling. On cooling, carbide molecules are formed only when there are nuclei present about which the particles may be precipitated. The greater the number of these nuclei the faster the precipitation and therefore the lower the hardenability, but the finer the grain size. It is thought that nuclei occur in the crystal boundaries, hence a coarse austenite crystal structure will present fewer opportunities for precipitation and therefore increase hardenability. This actually happens, and Fig. 20 indicates the depth of martensite formation in samples of the same steel when held at various temperatures in the austenite range to give different crystal growths. In each case the rate of cooling and temperature from which cooling took place were exactly the same. The steel concerned was 0·75% carbon steel. It is to be noted that this system of indicating hardenability by showing the hardness at

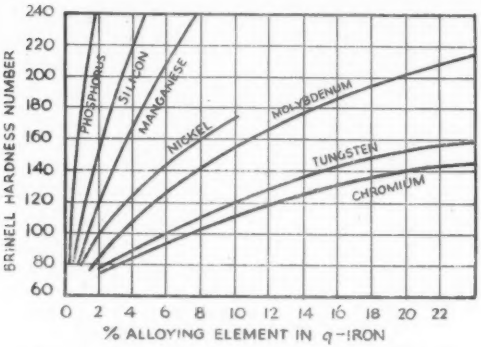

Fig. 21.—Hardening effects of elements dissolved in pure iron. Phosphorus, silicon, manganese, nickel, molybdenum, tungsten, chromium + 18.

varying radii in the cross section of a circular test piece is one of the most convenient for designating this physical property. The critical diameter for any material is that at which the specimen can be hardened throughout. Though coarse austenite increases the depth of hardness, it suffers from the disadvantage of much reduced toughness, because of the larger martensite crystals produced. Large grains have a greater tendency to retain internal stresses than small grains.

The optimum properties for steel are acquired by the tempering of martensite. This martensite cannot be produced in any but the smallest sections. It is primarily to overcome this that alloying of steel takes place, in other words, to increase the hardenability, to allow martensite and in some cases even austenite, to form at much reduced rates of cooling.

ALLOYS DISSOLVED IN FERRITE Practically all alloys, to some degree, are soluble in ferrite. This, in itself, because of the pegging of the ferrite crystal lattice with alloy molecules, must affect the mechanical properties, improving hardness and tensile strength. Fig. 21 shows the effect on hardness of varying alloys dissolved in pure iron. In comparison, Fig. 18 indicates martensitic hardness against carbon content for plain carbon steel. These two graphs clearly show the relatively small hardening effect of alloys dissolved in ferrite. Low carbon alloy steels where the carbon content is too small for thermal hardening to take place have a use in structural work where welding has to be carried out in situ. Heat treated carbon steels for this purpose will, of course, be considerably

weakened by the annealing effect of welding, whereas the stiffening due to the alloy dissolved in ferrite is not at all affected. Certain alloys in solution in ferrite, especially chromium where the concentration at the surface is not less than 1 atom of chromium to 7 of iron, act as a powerful corrosion inhibitor. Such steels also form the basis of one variety of stainless steel.

RELATIVE AFFINITY OF ELEMENTS FOR CARBON Most alloys have an affinity for carbon, combining with this substance forming alloy carbides. Where these are present in steels, the degree to which each individual alloy element combines with carbon depends on the relative affinity to carbon of the other alloying elements and the ferrite present. Also the proportion remaining in solution in ferrite is again dependent upon the relative affinity of all alloys and ferrite concerned for carbon. Nickel, silicon and aluminium, for instance, form no carbides and are, therefore, generally to be found in the ferrite phase. Most other elements, from manganese, which has only small carbide forming tendencies, to vanadium with the most powerful affinity for carbon, are usually present as carbides but also exist, of course, to a limited degree in solution in the ferrite crystals. All these elements have a greater affinity for carbon than iron. This means that when these are present less cementite will be formed and in heat treated steel the remainder of the carbon will exist in alloy carbides.

ALLOYING ELEMENT REDUCING MAXIMUM CARBON SOLUBILITY IN AUSTENITE Of paramount importance is the amount of carbon soluble in austenite in the presence of alloying elements. Fig. 22 shows the austenite part of the equilibrium diagram for varying quantities of titanium. As the alloying element is increased the maximum quantity of carbon in solution in austenite is gradually decreased because of the carbide forming tendencies of titanium. Thus it will be seen that 0·8% titanium leaves only 0·3% of carbon in solution in the austenite. Reflecting back to Fig. 18 showing the martensitic strength against carbon content, this implies that if each carbon atom were to form the same number of carbide molecules as cementite molecules, apart from the minor hardening effect of titanium dissolved in ferrite, the maximum hardness that could be acquired with such steel would only be about half that possible with a straight carbon steel. This, of course, is not a true state of affairs. The alloy carbide molecules contain different proportions of carbon atoms than do cementite molecules ; also compound molecules containing both alloy and iron carbide molecules are formed. Probably the pegging effect of these molecules, being of different size to cementite, also differs. What actually happens here is complex and not quite clear. There is

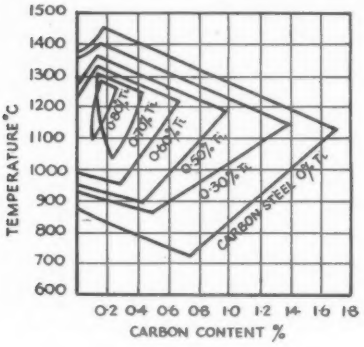

Fig. 22.—Influence of titanium content on carbon solution limitation in pure austenite + 18. 0% Ti; 0·3% Ti; 0·5% Ti ; 0·6% Ti ; 0·7% Ti ; 0·8% Ti.

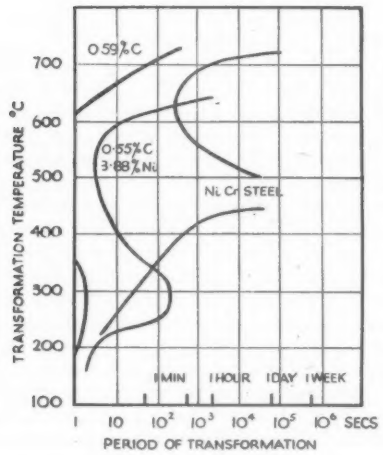

Fig. 23.—"S" curves showing start of austenite transformation for 0·59% C ; 0·55% C ; 3·88% Ni. Ni.Cr. Steel.

no doubt, however, that the maximum hardness obtainable in steel is that of a martensitic straight carbon steel and is not improved by alloying elements.

UNDISSOLVED PARTICLES AFFECTING GRAIN SIZE AND HARDENABILITY If more than 0·3% carbon be present in the steel, then that in excess of 0·3% will exist with the austenite as an insoluble titanium carbide. It has already been shown that for hardenability grain size of the austenite plays an important part. Inclusions in the austenite, such as separate carbides or non-metallic particles,

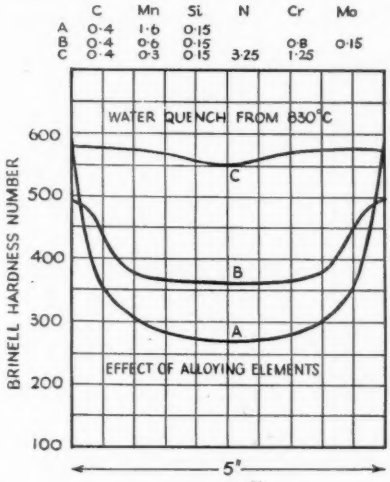

Fig. 24.—Hardness distribution on 3 in. dia. bar with water quench from 830°C.

	C.	Mn.	S.	Ni.	Cr.	Mo.
A	0·4	1·6	0·15			
B	0·4	0·6	0·15		0·8	0·15
C	0·4	0·3	0·15	3·25	1·25	

have the property of inhibiting grain growth. In a carbide forming alloying element therefore, if carbon be present in excess of that capable of being dissolved in the austenite, carbides will be produced that will inhibit grain growth and therefore reduce hardenability.

ALLOYS IMPROVING HARDENABILITY With the exception of cobalt, neglecting the effect of undissolved carbide formations, all alloys increase the hardenability, the carbide forming elements having

the most powerful effect. This quality implies that the " S " curves will be moved bodily to the right allowing more time for the cooling steel to pass the top inward bulge. Fig. 23 shows the " S " curves for different alloys. To obtain maximum hardenability combinations of elements have been found most effective. Fig. 24 shows hardenability of a cross section on 5 in. dia. bar for various steels, all conditions apart from the alloy content of the steel remaining the same.

It is possible by this means to obtain stable austenite at room temperatures by normal air cooling. This product, because of its uniformity of structure, is most useful as a corrosion inhibitor and is the basis of one series of stainless steels.

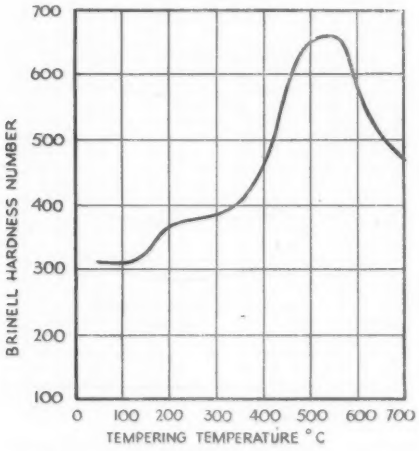

Fig. 25.—Tempering curve for pure austenite.

To review the hardenability situation, practically all alloys improve this characteristic in steel, though any undissolved inclusions in the austenite, whether they be carbides or non-metallic substances, restrict grain growth and hence reduce grain size, thus inhibiting hardenability.

RETAINED AUSTENITE EFFECT IN TEMPERING It is rare for martensite to be formed without any retained austenite. Up to about 25% retained austenite has little effect on the hardness of the basic martensite ; on tempering it disturbs the process slightly, in that at about 400° F. austenite is transformed into bainite according to

the expectation from the "S" curves. This gives a hardness slightly different to what would be expected, though it must be remembered that the hardness of bainite is nothing akin to that of martensite. Fig. 25 is an exaggerated effect of retained austenite on tempering shown for 1·8% carbon, 6% chromium steel, which has been quenched from 2,000° F. the structure produced being almost wholly austenitic state.

EFFECT OF FERRITE SOLUBLE ALLOYS ON TEMPERING Alloys which generally exist in the ferrite hardly affect tempering characteristics. Because of the pegging action the hardness is slightly increased and it is possible, by stiffening the structure, they decelerate, to some

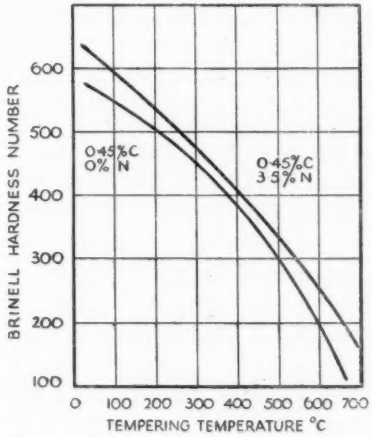

Fig. 26.—Influence of nickel on tempering.
0·45% C ; 0·45% C ; 3·5% Ni.

degree, the carbon migration. Fig. 26 shows the effect of nickel on a medium carbon steel.

CARBON COMBINING ELEMENTS ON TEMPERING The carbon combining elements, however, have a marked influence. Fig. 27 shows the effect of increasing chromium content. With 12% chromium the increase in hardness at 400° C. is often referred to as secondary hardening. It is thought that because of the migration of both the alloying elements and carbon, new alloy carbides are formed in the molecular state, this being responsible for the increase in hardness. This phenomena is made use of in high speed steels

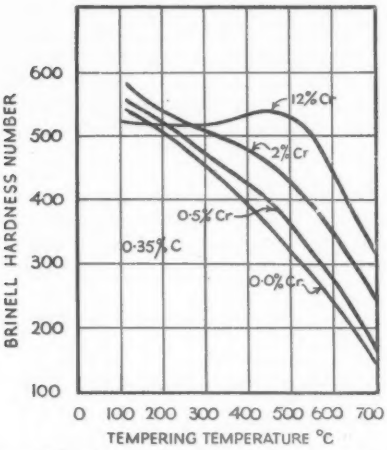

Fig. 27.—Chromium effect on tempering : 0·35% C steel. 0%, 0·5%, 2%, 12% Cr.

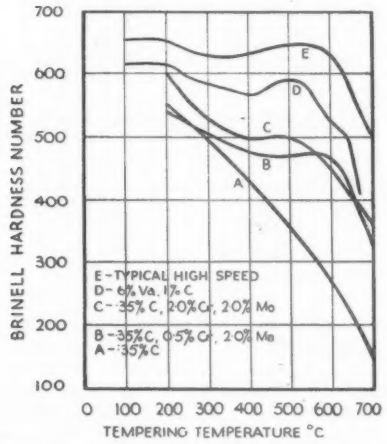

Fig. 28. - Influence of various alloys on tempering.
A. 0·35 C
B. 0·35 C ; 0·5 Cr ; 2 Mo.
C. 0·35 C ; 2 Cr ; 2 Mo.
D. 1 C ; 6 Va.
E. Typical High Speed Steel.

which require toughness and hardness at elevated temperatures. Combinations of alloying elements appear to smooth out the hardness curve parallel to the time axis. It is to be expected that the varying alloys being effective at different times give this desired cumulative effect. Fig. 28 gives the tempering characteristics of a number of alloy steels. One of these curves is for a typical high speed steel showing an almost constant hardness up to 600° C. Such a steel contains the excess in alloying elements necessary to produce undissolved alloy carbides in the austenite range. These hard carbide cutting particles remain firmly held in the tough matrix even at high working temperatures.

ADVANTAGE OF HIGHER TEMPERING TEMPERATURES IN RELEASING INTERNAL STRESS

It will be appreciated that for the same degree of hardness to be acquired in tempering quenched steel, alloys increase the tempering temperature. This advanced diffusion temperature allows greater release of internal stress and on these grounds alone alloying is advantageous.

It is imperative, also, that to obtain the optimum results perfect homogeneity in the austenite stage is essential. An area starved of alloy content on tempering will have a much reduced hardness compared with the rest of the material and as the weak link in the chain, will impair the advantages which ought to have been derived.

TEMPER BRITTLENESS

An interesting feature in tempering is the appearance of temper brittleness in certain steels in the vicinity of 480–540° C. Chrome nickel steels are particularly subject to this occurrence. The cause is not fully known but it is suspected that secondary precipitation occurs forming new compounds ; probably carbides are produced giving this adverse effect. Manganese and phosphorous appear to accentuate the trouble whereas molybdenum reduces the severity.

DISCUSSION

MR. T. A. WESTALL : You mentioned during your lecture that austenite was used for stainless steel ; I would like to know why this is done and is austenite used for any other purpose?

MR. F. WESTALL : At room temperature austenite consists of similar crystals containing carbon and alloying elements in solid solution in iron. The major cause of corrosion is electrolytic action between dissimilar metals. A material having a relative homogeneity such as austenite is, therefore, by no means as susceptible to electrolytic action as one consisting of crystals of different substances. A further reason for the resistance to corrosion of this specific material is that chromium is an important element in

austenitic alloy steel. In fact, the foundation alloy elements of one type are 18% chromium, 8% nickel. Chromium here exerts the same effect as it does in the non-austenitic chromium stainless steels.

A further austenitic steel, now of historic interest, is Hadfield's manganese steel. This consists of about 16% manganese and is wholly austenitic at room temperatures. To the best of my knowledge this was once employed, or intended to be used for railway lines. Mechanical action disturbs the unstable super-saturated solid solution and precipitation occurs forming martensite. The effect of the train wheels on such rails is therefore to produce a hard martensitic surface backed up by the tougher austenite.

MR. GRAHAM : Not being a metallurgist I would like to discuss high speed steel possibilities and to know just what happens when, on tempering a certain high speed steel we employ, the hardness is increased from 62 Rockwell to 72 Rockwell ; would there be any austenite present?

MR. F. WESTALL : It is difficult and perhaps almost impossible to free these alloy steels entirely from austenite. Doubtless some austenite must have been present, but the quantity would be insufficient to have much effect on the tempering characteristics. The reason for increases of hardness on tempering is the phenomenon of secondary hardness referred to in the latter part of my lecture. Fig. 28 was shown to clarify the point.)

MR. WADDINGTON : In the early stages did engineers find out how to harden steel practically or did they learn it from the scientist?

Mr. F. WESTALL : Science always comes second to practice. Inquisitive man attempts to discover and explain certain natural occurrences. In doing so he reveals further knowledge and propounds a theory. This theory not only explains what he has observed but also indicates what might be achieved. In this manner, practice and theory hand in glove, do we advance in knowledge and application of that knowledge.

MR. T. A. WESTALL : I notice you mention compound and foreign molecules; what is a compound molecule?

MR. F. WESTALL : To answer this question is, I am afraid, an excursion into atomic physics, of which I have only a most elementary knowledge. An atom consists of a number of electrons rotating round a central nucleus or proton, these electrons being arranged in one or more orbits. There is apparently a number of electrons to saturate an orbit and should the number in any orbit be less than the requisite number this particular atom will have an affinity for electrons in other atoms to complete the orbit requirement. Many atoms exist in numbers of their own kind grouped together in such a manner that the orbit of each atom has its full

complement of electrons, and likewise exist attached to atoms of other elements. This latter method forms the compound molecule.

QUESTION : In stressed concrete the maximum shear is in a direction of 45° to the applied force. How does this tie up with the theory of crystal breakdown due to shear?

Mr. F. WESTALL : Since the rupture of a crystal is due to shear it will be the maximum shear produced that is responsible for failure. This really becomes a question of principal shear stresses, the magnitude of these stresses and their directions being dependent upon the nature of the external applied loads. Where the force is that of single tension or compression, the principal shear stress is at 45° to the direction of the applied force and we can expect failure of the crystals to take place at this angle. This does not mean, however, failure along a continuous plane at 45°. The failure might occur on a number of planes at 45° to the applied load, these being in the form of serrations. If the number of planes be very great then the apparent appearance of the failure might be one of a single plane at right angles to the applied load.

QUESTION : Is it true that tensile strength is akin to hardness?

MR. F. WESTALL : Hardness is measured by such tests as indentation and scratching. In either case the external force is applied to the crystals and will be resisted by the internal restraining force of the molecules within the crystals until failure finally occurs. It appears to me that this is somewhat similar to the molecule restraining force action experienced in the case of a direct external load applied, as in the straightforward tensile test. Whether this be the reason or not, experimental results prove that different metals affect the hardness values in a similar manner to their effect on the U.T.S., and consequently that the hardness can be a reasonably good guide as to the U.T.S.

THE PLACE OF THE METALLURGIST IN PRODUCTION ENGINEERING

By E. R. GADD, F.I.M.

Presented to the West Wales Sub-Section of the Institution, 3rd February, 1950

METALLURGY has been defined in general terms as " art and science applied to metals " and more specifically as " the extraction of metal from its ores, refining, alloying, shaping, treating, study of structure, constitution and properties." As far as the engineer is concerned, he is mainly interested in the physical, chemical and mechanical properties of metals and their alloys.

All engineers are of course not necessarily interested in the same properties. The electrical engineer looks for electrical conductivity, magnetic permeability, etc. ; the civil and general engineer, mechanical strength and resistance to corrosion ; the aeronautical engineer, and in this I include engine and airframe, is interested in a very wide range of properties in which density looms large. No less important are strength at normal and elevated temperature, heat conductivity, expansion under heat, corrosion and scaling, etc.

HISTORY OF METALLURGY

In considering the broad definition of metallurgy as " art and science applied to metals," one is very much tempted to indulge in a discourse on the achievements of some of the very early users of metals, as revealed by the metallurgical examination of ancient implements. There is no doubt that steel was made and used in ancient Egypt as far back as 3000 B.C. and there is evidence that there was also some knowledge of heat treatment, including case-hardening of steel at that time.

Up to about 100 years ago, metallurgy was all art and very little science. From 1850 onwards the application of science to metallurgical problems has steadily increased, and today the tempo of development is so rapid that it is difficult to keep pace with metallurgical progress. Many research organisations have been built up for the furtherance of metallurgical knowledge. Firstly, there are the universities and Government establishments such as the N.P.L. who are engaged on exploring fundamental properties of metals and alloy systems.

Then there are the industrial research associations as exemplified by the British Iron and Steel Research Association and the British

Non-Ferrous Metals Research Association. The metal producers themselves often have large research laboratories devoted specifically to the study of their own products.

Finally there are the research departments attached to the engineering organisation itself. Metallurgical research in these engineering concerns might be more properly designated as development research, since the greater part of the work carried out is often what might be called short time research, and it is usually devoted to specific problems relating to the particular engineering project of the company. It will be thus seen that there is a very big body of metallurgical research workers devoted to the service of the engineer. It would be quite impossible for the engineering industry to maintain progress without this background of metallurgical study and research.

Having briefly dealt with the research angle in general terms, I would like to deal more specifically with the work of those metallurgists who act in an advisory and inspectional capacity in a modern engineering works.

METALLURGICAL SPECIALISTS

In order to advise the engineering side, the metallurgist must firstly keep himself informed of all new metallurgical developments emanating from the research organisations not only in this country, but from all parts of the world.

Secondly, it may be necessary for him to carry out short range researches in his own laboratory, in order to deal with pressing problems arising out of the firm's engineering projects.

To carry out metallurgical research successfully even on a relatively small scale, it is found necessary to build up a team of specialists to cover the four main metallurgical sections—Metallography, Physics, Chemistry and Mechanical Testing.

The metallographist is a specialist on the microscopic examination of metals, and I want to say a good deal more about him later on.

The physicist, as the name suggests, carries out tests to determine the physical properties of material, such as heat conductivity, electrical conductivity, magnetic properties, expansion of materials under heat, density. He may extend his field to cover atomic structure and crystallography, spectroscopy and other work peculiar to his particular expert knowledge.

The chemist has often a particularly wide field to cover, extending outside the bounds of strictly metallurgical work. On the metallurgical side, he deals with the analysis of metals and alloys and the control of plating solutions. Beyond that he may become involved in fuels and lubricants, cutting compounds, trade wastes and a host of other chemical jobs.

The mechanical testing expert, sometimes described as a metallurgical engineer, is responsible for such tests as tensile, torsion, fatigue, creep, hardness and abrasion, and in some organisations these tests may be carried out on components as well as test samples.

MAIN WORK OF SPECIALISTS

The work of these specialists can be summarised under the following main headings :

1. Properties of metals and alloys.
2. Application of metals and alloys in the form of components including the investigations of failure of components.
3. The exploration of metallurgical processes as exemplified by surface hardening, corrosion protection, also the melting and casting of metals.

These three groupings give a clue to the advisory side of metallurgical work in a modern engineering concern. For example, properties of metals are of direct interest to the design department. Then the application of new metals in the fabricated form comes mainly into the province of the development section. Finally, metallurgical processes are very much the concern of the production department. In fact, a metallurgical process seldom becomes perfected until it has withstood the searching requirements of quantity production.

I would hasten to point out that these divisions are not really so sharply defined as my words suggest. All phases of design, development, and production are closely inter-related but from the metallurgical point of view they can be broadly separated in the way shown. The point I want to make is that the metallurgist comes in at all stages, design, development and production. It might be very interesting to deal with all these aspects of metallurgical interest in detail, but time does not permit. I thought it might be worth while, however, to dwell for a short time on the work of one of the specialists, the metallographist, since his work can be of such importance to the development and production side. His link with the production side is often through the Production Metallurgist of whom I shall have more to say later.

THE METALLOGRAPHIST

I have already mentioned that the metallographist is an expert in the study of metals by the microscope. The first essential in the examination of metals by the microscope is that the metal sample shall be polished by a process of cutting and not smearing the surface. This is done by a succession of grinding and emery paper operations, taking the specimen down stage by stage with finer and finer abrasives until the final polish, which consists in treating the surface with a rotating

cloth covered wheel treated with a very fine abrasive such as alumina or chromium oxide.

When viewed under the microscope most metals will show a blank surface with no discernible details. If, however, the surface is now lightly attacked by a suitably selected etching reagent, it will be found that what looked like an uninteresting homogeneous piece of metal now shows patterns of graded light and dark areas which to the experienced metallographist reveals many of the innermost secrets of the metal.

Now how is such information useful to the engineer? Suppose we take steel as an example.

In straight carbon steels the actual carbon content can be estimated with a fair degree of accuracy. The heat-treatment history of carbon and alloy steels can be estimated and such features as overheating at some earlier stage of processing and the conditions of the latest heat-treatment operations can be observed. The presence of case-hardening whether by carbon or nitrogen is readily seen. Also loss of carbon from the surface, usually called decarburisation, is very evident.

Grain boundary weakness, internal cracks and non-metallic impurities are readily noted.

The structures of non-ferrous alloys are also readily revealed by micro-examination. While the microscope is the metallographist's main tool, he is usually highly experienced in the interpretation of metal fractures and can quickly detect whether a part has failed by normal tensile overstress, by impact, or by fatigue. These fractures have certain distinctive features which are relatively easy to interpret in the case of steels, but more skill is required when light alloys are involved.

Another branch of the metallographist's work is the examination of sections of components involving deep etching to show the grain flow of the material. Steels lend themselves particularly well to this method of examination, although quite good effects can be obtained on non-ferrous alloys if sufficient care is taken in choosing the right etchants. It can be seen from this brief review of the work of the metallographist that by initial examination of fractures, microscopic examination and deep-etching for grain structure, he is particularly well equipped to make examination of failed parts. With the addition of a simple hardness tester, he can often tell the engineer all that he needs to know about why a component has failed.

If the exact composition of the material involved in the failure is in doubt and it is necessary to check against a material specification, then the chemist is brought in to carry out the necessary tests.

This is very necessary in those cases where a complaint against the supplier of the material is envisaged.

PRODUCTION METALLURGIST The Production Metallurgist, of whom I have so far said very little, works in close relationship with the metallographist since many of his queries can be settled very quickly by resort to microscopic examination.

In many works organisations, the Production Metallurgist may be the only metallurgist, and his ability to serve the Production Engineer will depend on his training on the one hand, and the equipment he is allowed to possess on the other. A small mechanical test section to make routine tests on incoming materials is often provided, but if the use of a microscope can be added, the scope of the metallurgist becomes very much increased. This fact will be appreciated from my recent remarks on the role of the metallographist.

The Production Metallurgist may have a wide range of activities according to the scope of the engineering organisation in which he is employed.

In a very comprehensive paper presented to this Section of your Institution last year, Mr. Nourse on the general subject of inspection dealt at considerable length with metallurgical inspection. I do not propose to go over all the ground again. All the multitudinous tests of materials, castings, components, plating and anodising solutions are appropriately referred to in that paper, set out and dealt with in masterly fashion.

I would, however, like to remind you briefly of a few of the Production Metallurgist's jobs. In his capacity of metallurgical advisor to the Inspection Department, he becomes responsible for setting standards of acceptance on incoming raw material, and carries out tensile, impact and hardness check tests on such material. He keeps a close watch on heat treatment and is expected to investigate reasons for failure of parts to develop mechanical strength, hardness, or the correct depth of case. In the particular organisation of which I am a member he is responsible for the maintenance of pyrometers and all temperature measuring equipment. He also controls X-ray plant and sand testing in the foundry.

Standards of acceptance on finished parts are decided by the Production Metallurgist, and in this connection he controls methods for the detection of surface defects—for example, magnetic crack detection, etching, oil and chalk tests, etc.

He is interested in plating processes and receives reports from the chemical department on the routine checks of and additions to plating solutions.

He watches over other metallurgical processes such as white-metalling, brazing, welding and deals with queries arising from these processes.

The Production Metallurgist has to grapple with innumerable daily queries and problems, a big proportion of which he is able to deal with without other assistance. There are occasions of course when production problems arise of such an obscure nature that the whole of the metallurgical strength has to be called into play, the chemist, the physicist, the metallographist and the metallurgical engineer. The Production Metallurgist is indeed fortunate if he is able to call on such help to assist him in solving his problems.

IMPORTANCE OF THE METALLURGIST My paper so far has been devoted mainly to what might be called metallurgical laboratory organisation, intermixed with a few special details of procedure. The engineer might be disposed to say—" Yes, we know something about metallurgical control of our processes, what has the metallurgist really produced of outstanding importance?"

Well, the simplest and most direct answer to that is that engineering would not exist at all if it were not for the metallurgist, and of all metallurgical developments the production of iron and steel in quantity ranks as one of the most important, if not the all-important, contribution to the progress of engineering.

The original method of extracting iron from its ores consisted roughly of heating together iron ore and charcoal. From this a tough, porous, pasty mass of iron was produced, which was afterwards hammered into a compact mass during which operation slag and other impurities were ejected. Later, when furnace designs improved and mechanically produced forced draught took the place of natural draught or man-made draught, higher temperatures were produced and some of the first cast iron came into being. The cast iron was a mixed blessing. In some ways it was welcomed as being a new metal which could be cast into convenient shapes. To make iron from it, however, a process of decarburisation had to be used before it would respond to working under the hammer. Much experimental work went on around 1700–1800 in an effort to find ways of producing iron and steel in reasonable quantities, but it was left to Bessemer really to tackle the problem in a big way and the introduction of the Bessemer converter made possible the production of steel in tons where before steel could only be produced in lb.

The work on the converter was carried out around 1850, and from then on the art and science of making steel in big quantities has progressed with ever increasing tempo.

The application of scientific research to ferrous materials has produced numerous valuable materials for the use of the engineer.

The first steels were of the straight carbon type, many of which still have their use today. Low and medium carbon structural steels are made in vast quantities for general engineering purposes. The higher carbon steels have their special application in the form of such parts as cutting implements and springs.

The introduction of nickel and chromium widened the scope and application of steels, and high strengths with considerable toughness became possible. At the same time the metallurgist was forced to find materials to cut and machine the steels of improved properties. High carbon steels gave way to steels containing considerable proportions of tungsten, and the steels now generally grouped under the name High Speed Steel came into being.

One of the greatest contributions to ferrous metallurgy occurred in 1914, when Brearley first discovered that if chromium was added to steel in sufficient quantity the corrosion resistance could be enormously increased. The early stainless steels of the 13% Chromium type were only the beginning of a vast range of stainless and heat resisting types of steel whose number still continues to grow, to such effect that the poor metallurgist's brain reels at attempts to commit them to memory.

Some of the modern highly alloyed steels are so rich in elements other than iron that one finds some difficulty in deciding whether they should continue to be designated ferrous materials.

The ferrous metallurgist has made great studies in the production of magnet steels and among numerous other developments, mention should also be made of the low expansion alloys of the Invar type.

DEVELOPMENTS IN CAST IRON Coming under the heading of ferrous metallurgy, some reference should also be made of developments in cast iron. Earlier cast iron had tensile strengths of 12/13 tons/sq. in. Modern methods of manufacture, particularly those producing the so-called nodular graphite, can offer the engineer tensile strengths up to 30 tons/sq. in. while retaining good bearing properties.

Another very great metallurgical development has been the introduction of the cemented carbide materials, the most well known being that of the tungsten carbide type used for cutting tools. The increasing interest in powder metallurgy offers great scope for improvement in material for cutting purposes, although this is not the only possible line of enquiry. There is hope that powder methods may produce some outstanding material for high temperature application, and such components as turbine blades come to mind as being suitable for manufacture by these methods.

ALUMINIUM AND ITS ALLOYS On the non-ferrous side the greatest advances have been made in aluminium and its alloys. The first big step forward came when Wilm in 1911 discovered

that aluminium alloys reacted to what we now call age-hardening, and the first high strength aluminium alloys were born. The earlier alloys of this type were called duralumin, and in fact this name is still with us today, used rather loosely to cover all alloys of high mechanical strength. Much progress has been made since those early days in aluminium alloy development, and whereas the earlier duralumin produced tensile strengths of 25 tons/sq. in. with 0·1% proof strength values of 15 tons/sq. in., it is now possible to have alloys of a tensile strength of 32 tons/sq. in. and 0·1% proof of 28 tons/sq. in. The values quoted are minimum values in each case, and in actual fact it is not uncommon to obtain tensile figures nowadays approaching 40 tons/sq. in. One of the important process developments which have come with the advance in mechanical properties of aluminium alloys has been the production of duplex sheet. The high strength aluminium alloys have not such good corrosion resistance as pure aluminium. In an effort to combine the best tensile and corrosion resistance, it has been found possible to produce a composite sheet which has pure aluminium on the two surfaces and with high tensile material sandwiched between. Such material is used widely for the stressed skin of the modern aircraft.

Time does not permit of a detailed reference to the many developments in the bronze field, but some reference should be made to the increasing use of the so-called lead bronze as a bearing metal. For some applications copper-lead alloys and bronzes containing lead have replaced the traditional white metals and phosphor bronze. The latter alloys have by no means been superseded, but a wider variety of bearing materials are now available to the engineer.

Magnesium is a metal which has come into increasing use in the last few years. The prejudice against this metal from the point of view of corrosion and fire risk has gradually been broken down.

Magnesium and its alloys can be protected against corrosion very effectually by surface treatments. A relatively new development has been the production of magnesium alloys of higher purity—that is almost completely free from iron and nickel. It has been found that if the iron and nickel contents can be kept sufficiently low, the corrosion resistance of magnesium is extraordinarily good.

The fire risk with magnesium remains, but the risk is not really serious ; in fact it is extremely difficult to burn a piece of magnesium in any form other than powder or thin sheet.

ELECTRICAL PROCESSES Of the many metallurgical processes which interest the engineer, electrodeposition for corrosion protection or ornamentation is one of the most important.

The introduction of chromium into the series of metals readily deposited has opened up a big field of usefulness for this metal. Chromium is also finding an increasing application for those cases where its combined wear and corrosion resistance are particularly suitable, i.e., for motor car cylinder blocks and liners and for building up worn parts.

Among the other electrical processes mention should be made of the anodising of aluminium, the process which builds up the naturally resistant oxide skin on aluminium. The coating not only provides excellent corrosion resistance, but lends itself to impregnation by inorganic dyes so that attractive finishes can be produced.

NITROGEN HARDENING Of the many other metallurgical processes, I would select nitrogen hardening as being one of the most beneficial to the engineer. This process has many advantages over carbon case-hardening. The three main advantages are :—

1. The component can be finish machined prior to nitrogen hardening. No quenching is required and distortion is negligible.
2. The case does not soften until the temperature of reheating exceeds the original nitriding temperature (usually around 500° C.).
3. The case of a nitrogen-hardened component is in a state of compressive stress, which results in the fatigue strength of the steel being increased markedly, particularly under conditions of stress concentration.

LOOKING AHEAD Having briefly dealt with some of the more recent achievements in the metallurgical field, what of the future? Well, the engineer is never satisfied with what the metallurgist gives him. In this world of keen commercial competition, it is hardly to be expected that the engineer will ever say that he can manage "very nicely thank you" with existing materials and this is as it should be. Metallurgical research, however, is very like any other research. Progress is usually slow and laborious, with occasional bursts of brilliance such as the discovery of stainless steel or the age-hardening characteristics of certain alloys of aluminium.

There are still enormous fields of enquiry. New metals such as titanium are exciting interest, but don't expect too much from this metal for a few years yet. The development of alloys for high temperature service is proceeding apace, the advent of the turbine engine has promoted feverish research into new alloys, ceramics, and into mixtures of metals and non-metals. Out of this research

will emerge new material for high temperature application, and the failures may find application in other directions.

Coming back with a bump to more immediate problems, you will have noted that I have studiously avoided any reference to that evergreen bane of the production engineer—machineability. Some attempts have already been made to deal with this problem. The earlier methods involving the raising of the sulphur content you will be well acquainted with.

More recently considerable success has been achieved by the introduction into steel of a small quantity (about 0·25%) of lead. In many ways this seems to be a better answer than that based on high sulphur. When properly made the lead in these steels appears to exist in such a fine state of dispersion that it cannot readily be detected with a microscope, so that the slag streaks usually associated with high sulphur are substantially absent.

For most engineering applications leaded steels are perfectly satisfactory, but a warning should be given regarding the necessity of adequate ventilation when welding steels of this class.

The metallurgist is in the unfortunate position of trying to reach new heights in strength and hardness, greater resistance to corrosion and scaling, improved resistance to wear and abrasion, and yet he has to ensure that the material he produces can be machined and fabricated.

This problem of fabrication will always be with us, and it is not going to get any less.

THE WORK OF PERA It is for this reason that everyone, engineer and metallurgist alike, welcomes the programme of work being carried out by P.E.R.A. on machineability and formability. Both problems are extremely difficult to plan and to carry out. The problems are difficult because of the large number of variables, but from what I have seen of the programme, I feel that the work is being carried out in the right way.

This is a good example of co-operation between metallurgist and engineer both working to a common end.

In spite of what production engineers may think of the metallurgist, I can assure you that the good metallurgist in thinking up new materials or processes does and must have in view some thoughts on the ultimate method of fabrication, and it is a good thing for the metallurgist and engineer to make close contact at an early stage of any new material development. The work of the metallurgist and engineer is complementary and one can hardly exist without the other.

In my talk tonight, I have deliberately avoided a detailed description of that aspect of metallurgical work which deals with

routine control. Much already has been written and said on this subject. I have talked a little about metallurgical methods and a little about metallurgical achievements, and I hope that what I have said will have increased and heightened your interest in metallurgy and the metallurgist.

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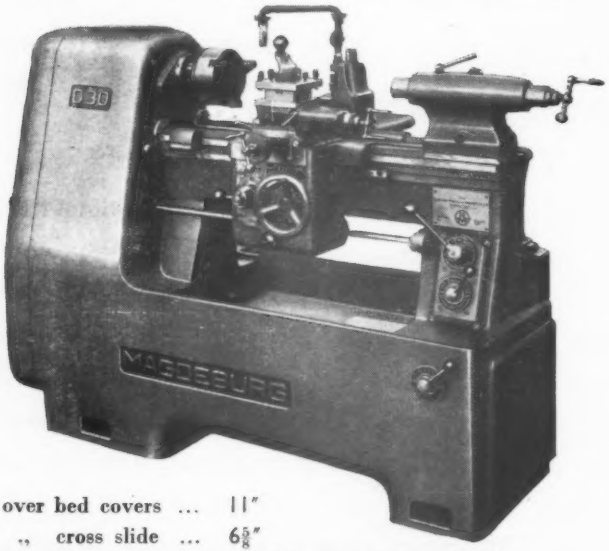

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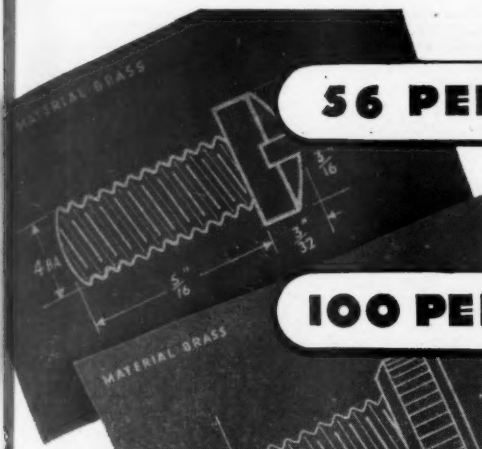

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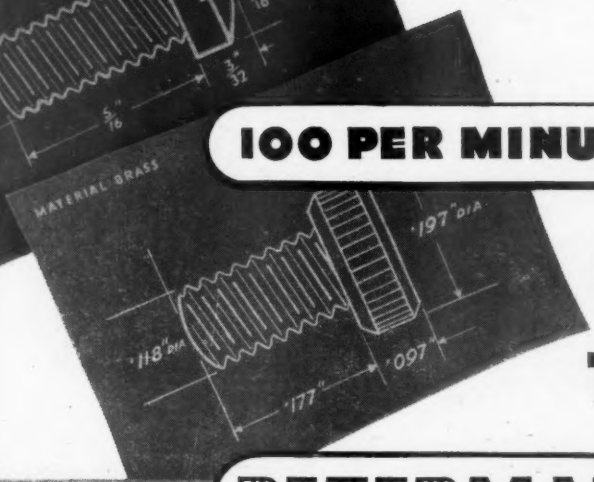

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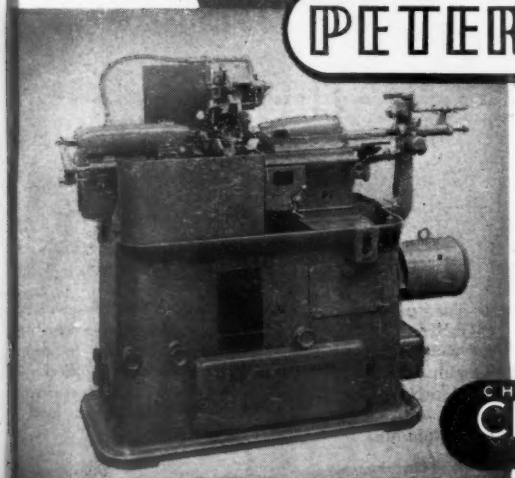

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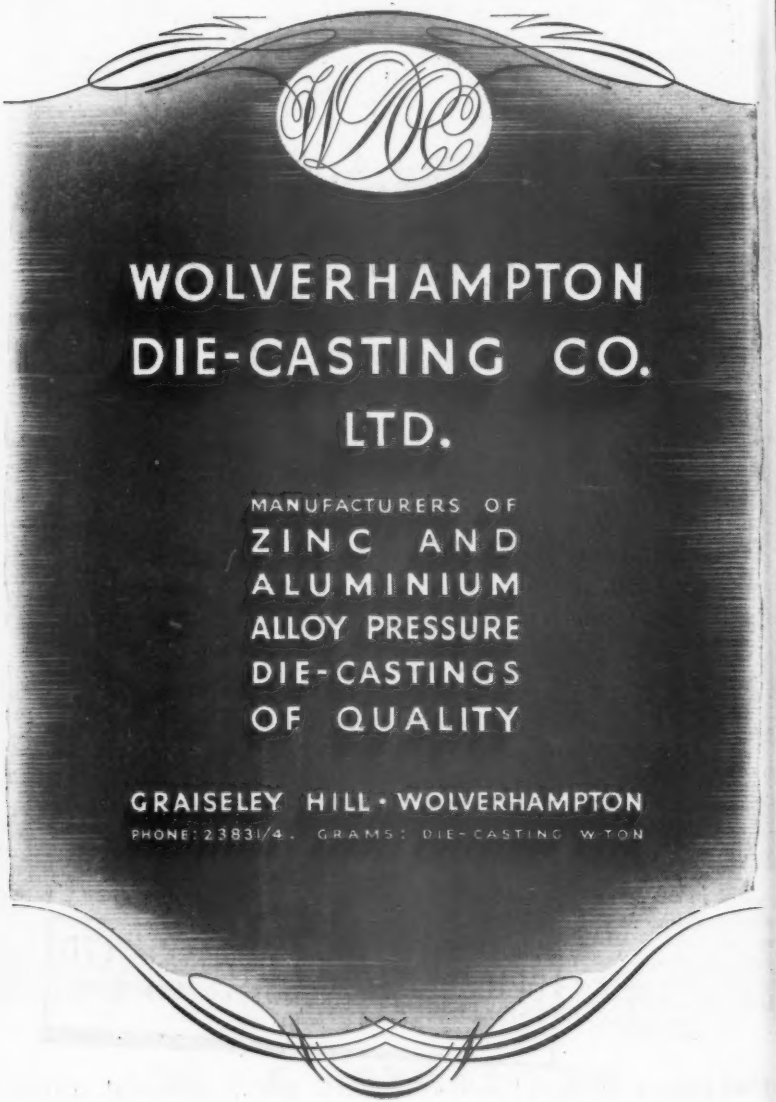
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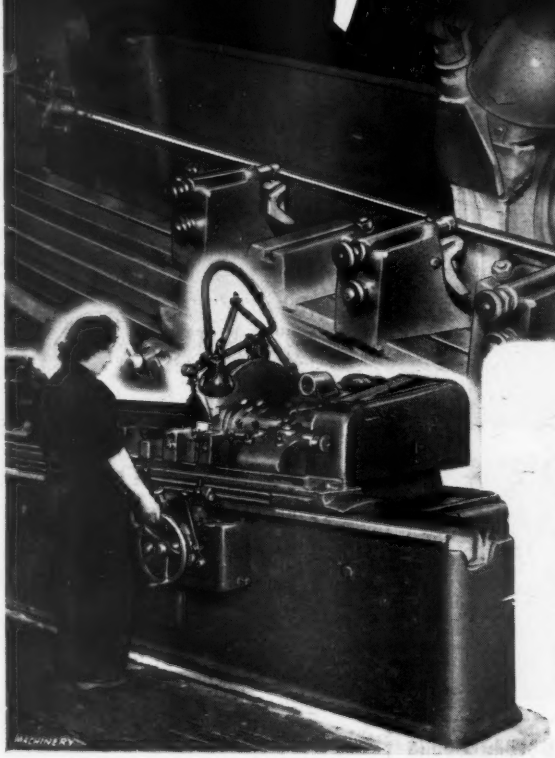

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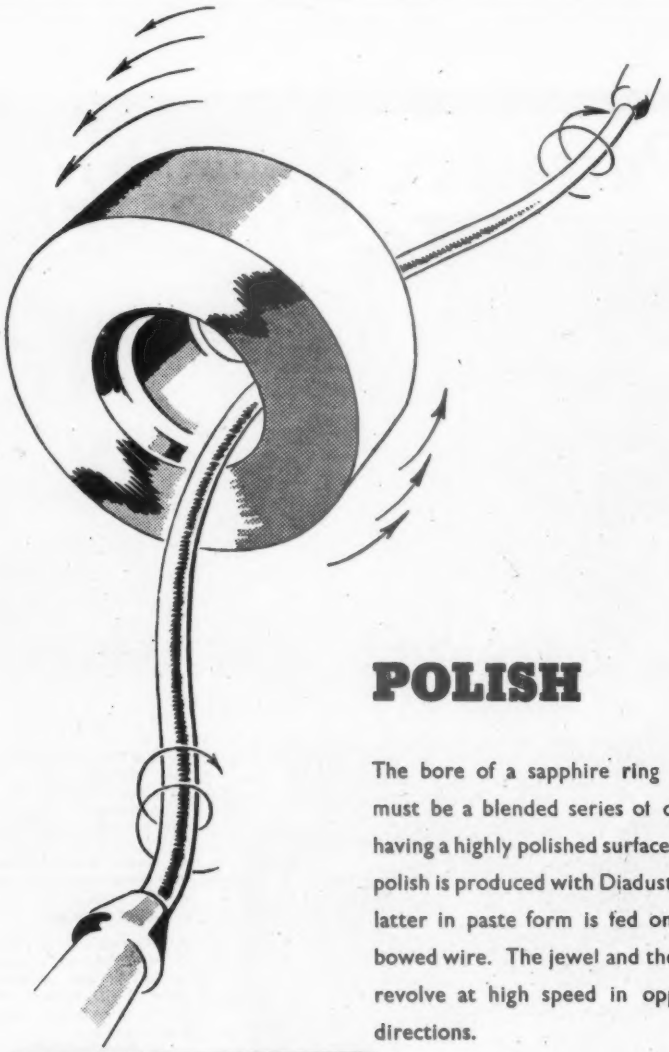

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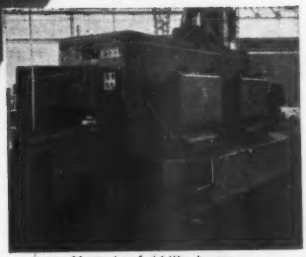

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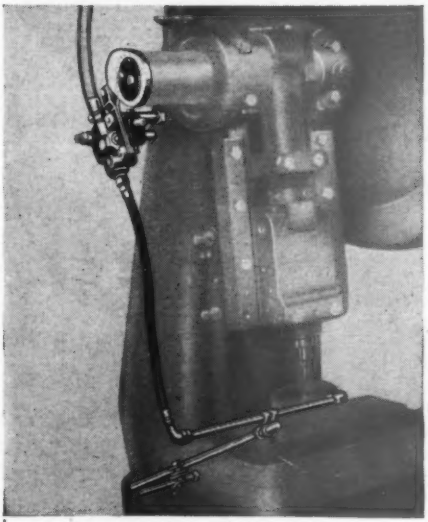

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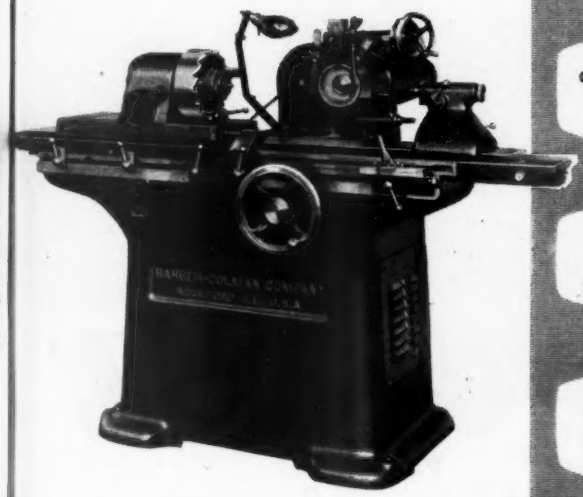

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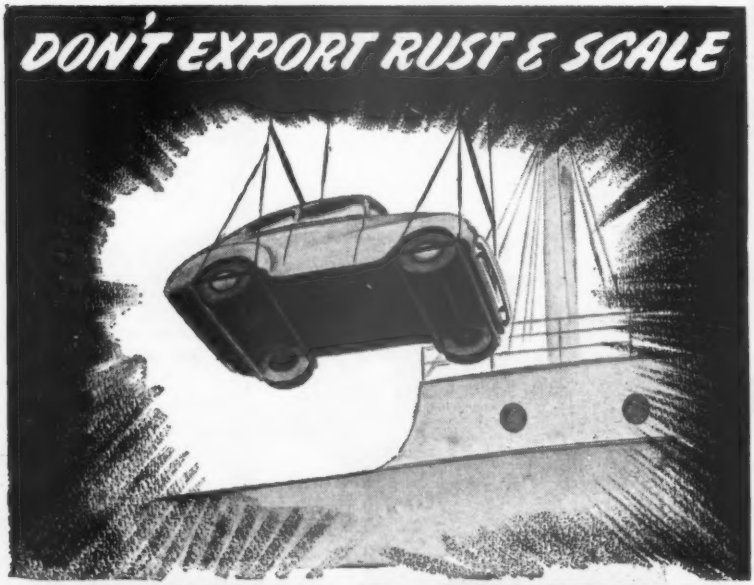

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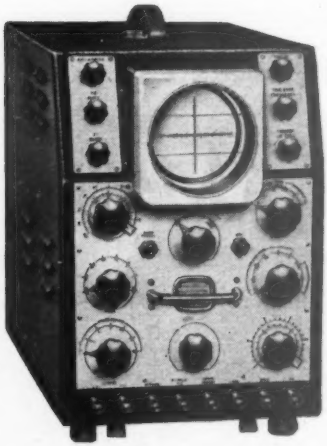

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The Double Beam Tube presents two simultaneous independent traces over the full diameter of a 90 mm. screen and provision is made for the measurement of both input voltage and time upon the calibrated dials of the Instrument. The Oscillograph is particularly suitable for obtaining permanent photographic records using the Camera Model 1428, for which a Motor Drive Attachment, Model 1429, is available.

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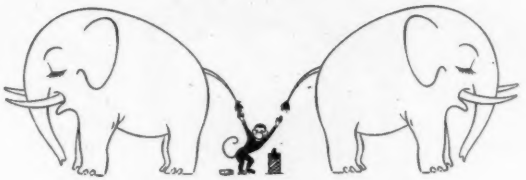
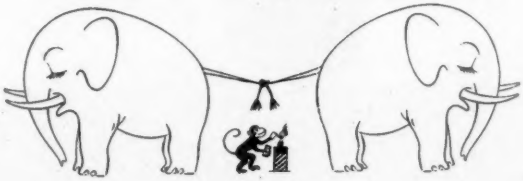
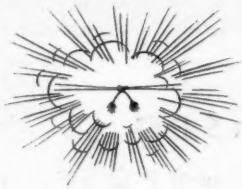




TENSILE  STRENGTH

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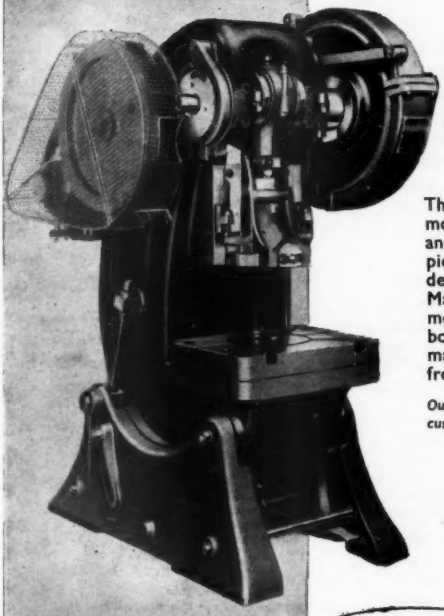

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The L.N. 40 Press illustrated here is a most useful machine for general purposes, and affords extreme facility for the piercing etc, of large area work, as it is designed to give full load without tie-bars. Made both geared and ungeared, this model exerts 40 tons pressure near bottom of stroke, and is only one of the many fine presses selected at random from the H.M.E. comprehensive range.

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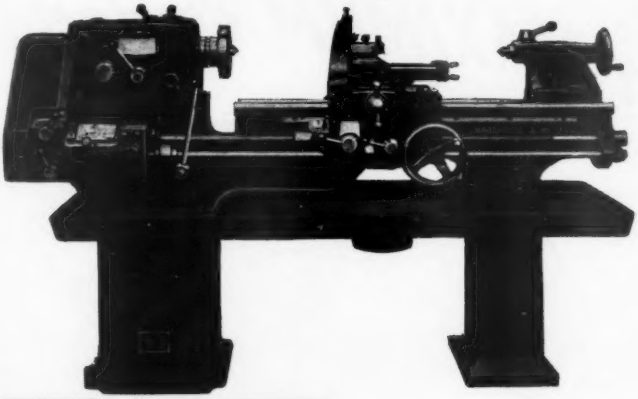

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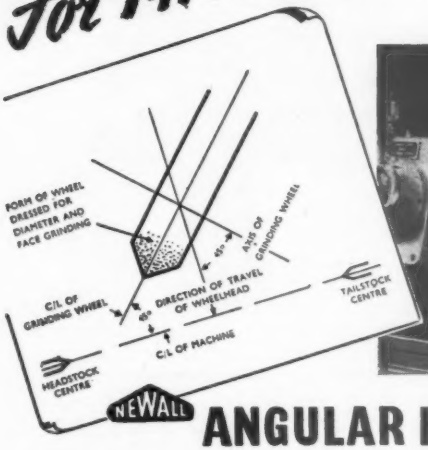

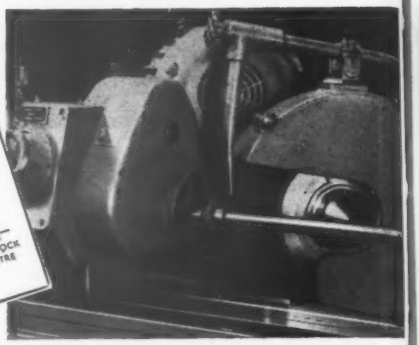

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The Newall Angular Head Grinder has been developed for use on components where it is necessary to obtain a super finish on a diameter and a face. The face, instead of being ground with a narrow lip formed on the side of the wheel, is finished with the actual periphery of the wheel, the wheel at 45° to the centres of the machine.
The inherent precision of Newall grinders—such as the machine described here—speeds production and eases the lot of management and worker alike.
May we supply full data on this interesting newcomer?

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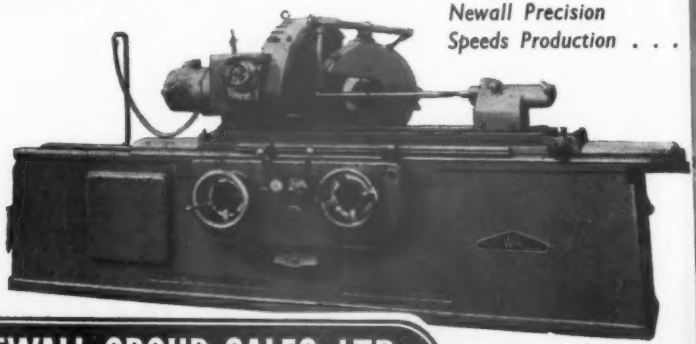

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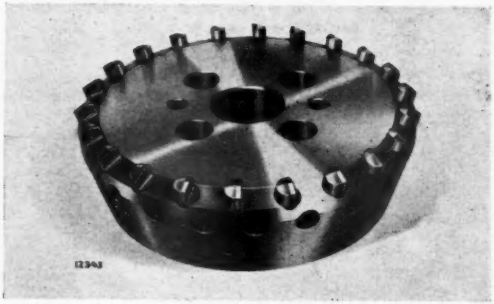

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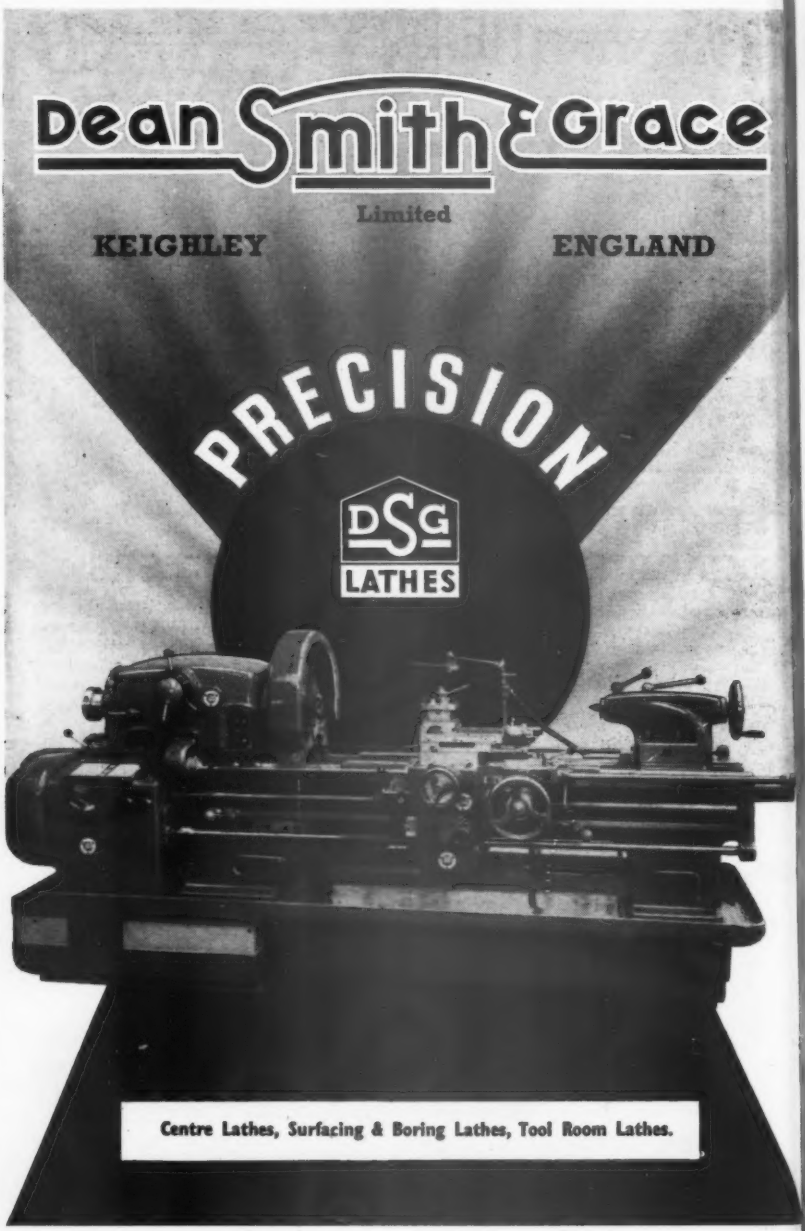
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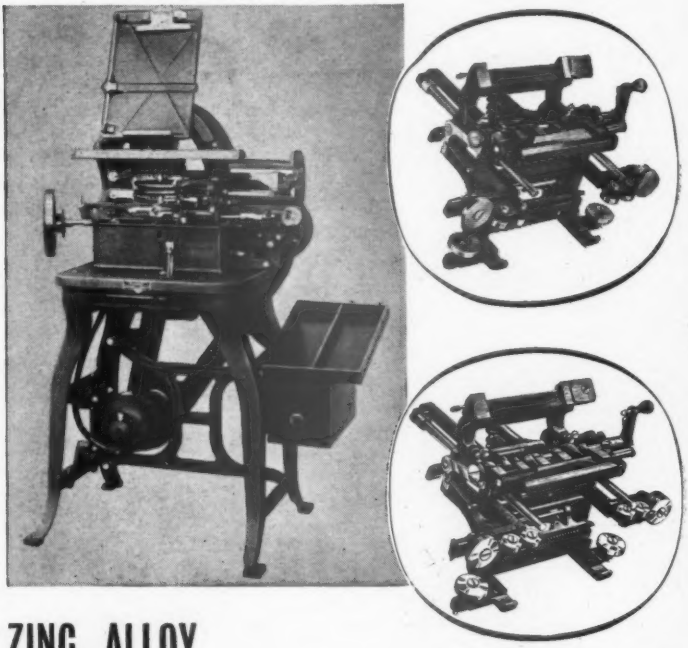

ZINC ALLOY DIE CASTING makes a difference!

Difference to what? The inset photograph shows an assembly of six zinc alloy die castings; below it is a sketch of the old model using iron, brass and gun metal castings. They look much the same, but which would you rather buy?

When the makers of the addressing machine adopted zinc alloy for the plate holding mechanism, they exchanged 35 machining operations for five in one component alone — with a cost reduction of 75 per cent! The other five die castings each effected savings of 25–50 per cent. In addition, the exact dimensions of the die castings made assembly easier, and their fine surface has smartened the product.

Some facts about zinc alloy die casting

Speed of production is an outstanding feature of the die casting process — the shortest distance between raw material and finished product. Zinc alloys are the most widely used of all metals for die casting because they yield castings with the following qualities:

ACCURACY: Castings can be made practically to finished dimensions and need little or no machining.

STRENGTH: Good mechanical properties for stressed components.

STABILITY: Close tolerances are maintained throughout the life of the casting.

British Standard 1004

It is essential that alloys conforming to B.S.1004 should be specified for all applications.

The Association welcomes enquiries about the use of zinc alloy die castings. Publications and a list of Members are available on request.

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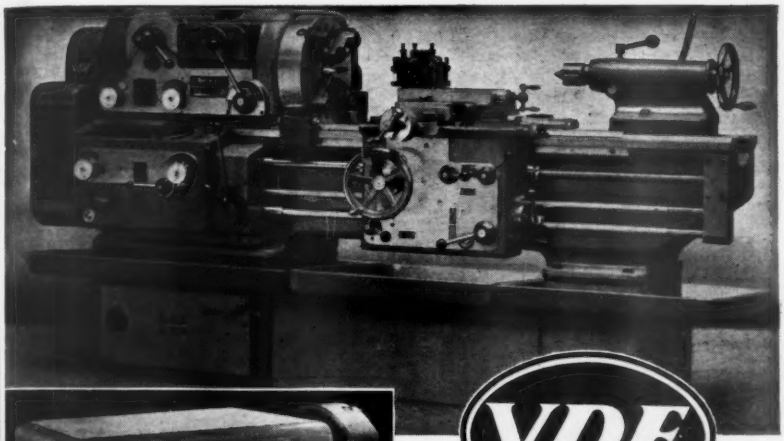

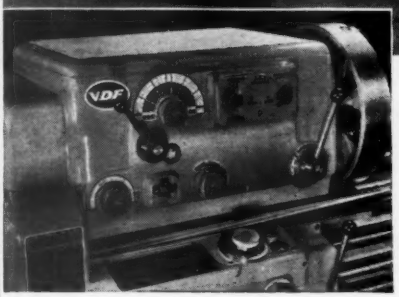

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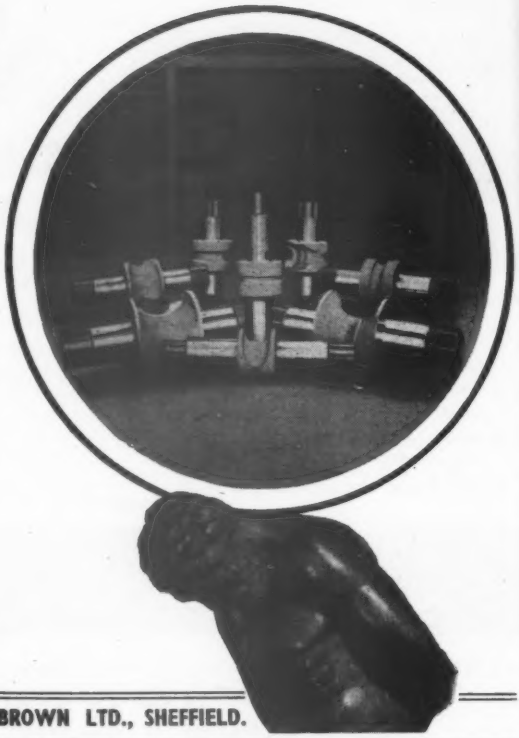

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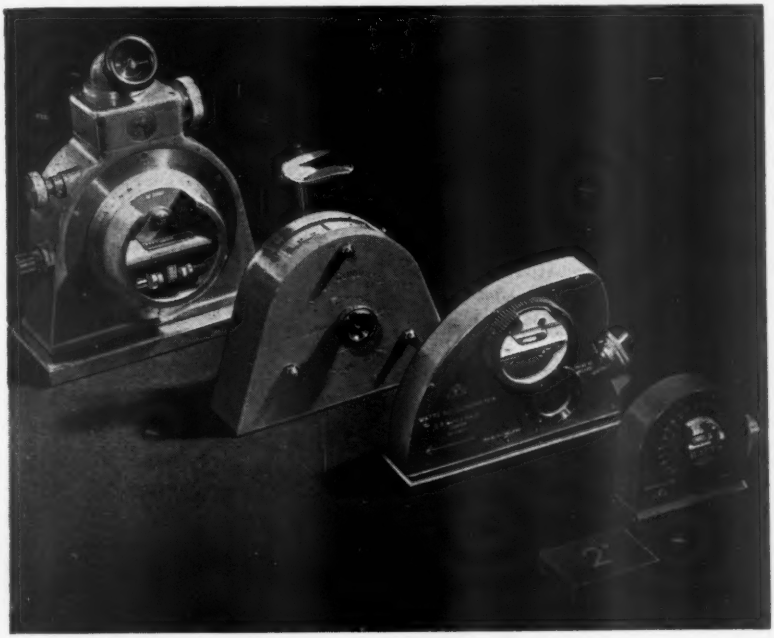

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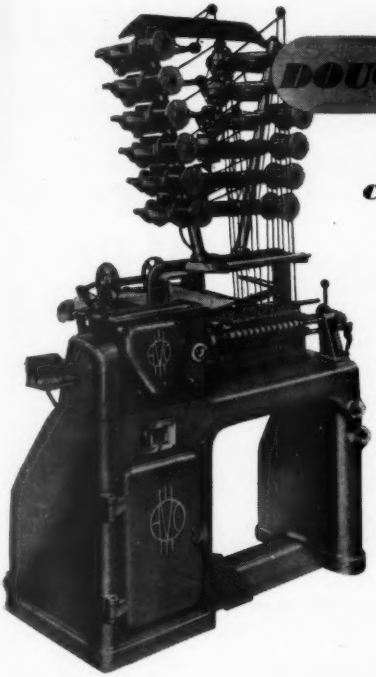

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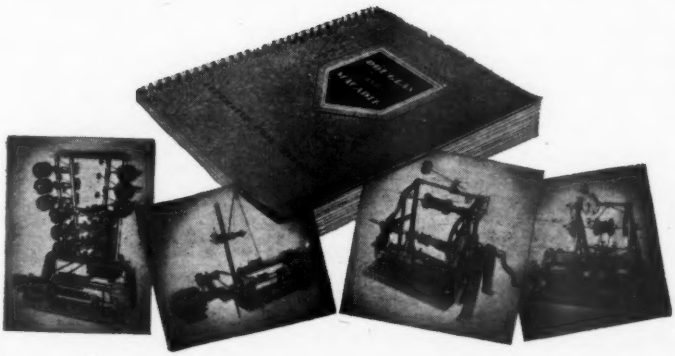

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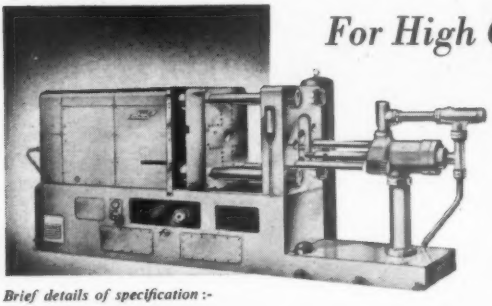

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Brief details of specification :-

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Plunger diameters	**1¾ to 3¼ ins.**
Pressure on material ...	**6,150-23,000 lbs. sq. in.**
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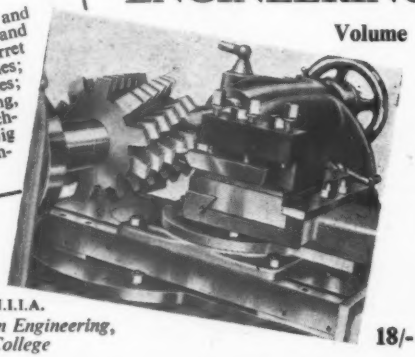

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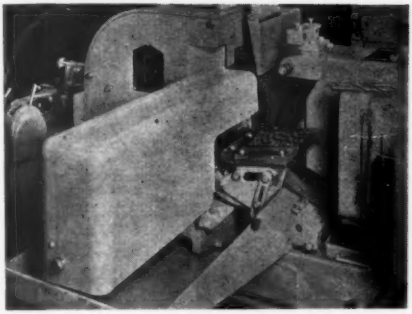

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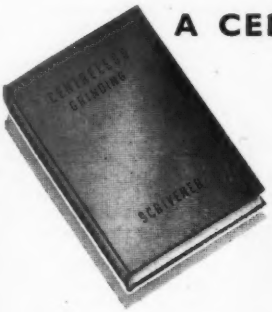

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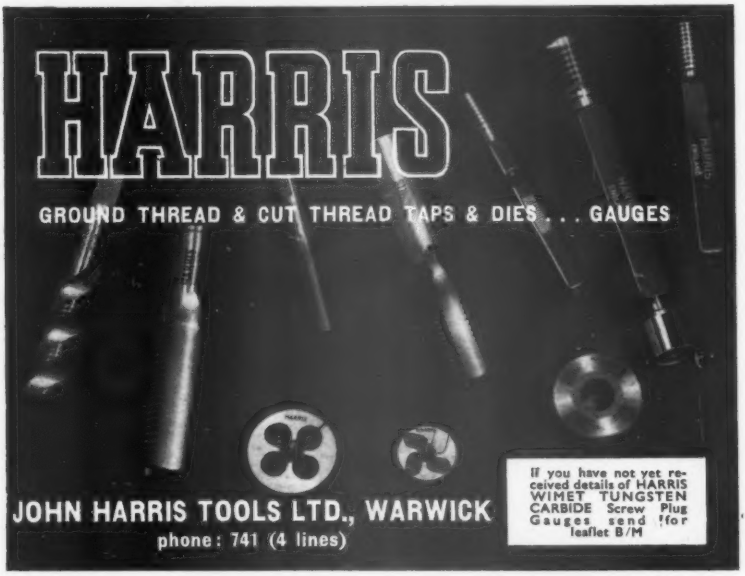
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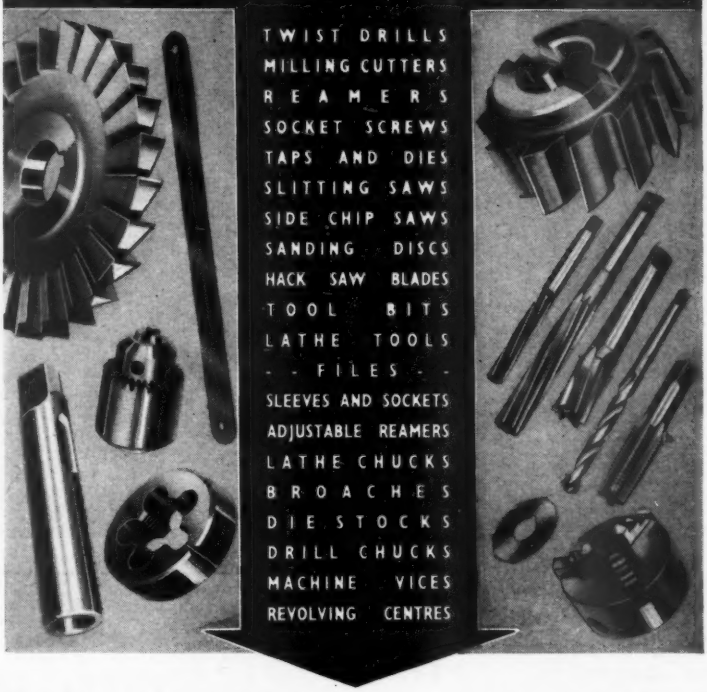

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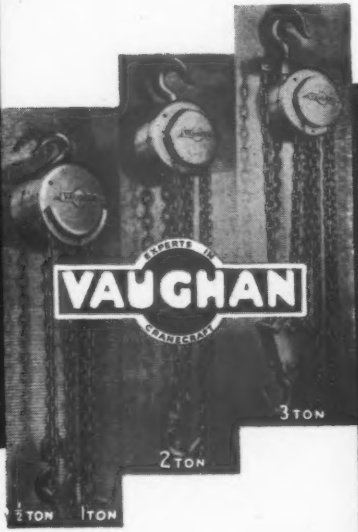

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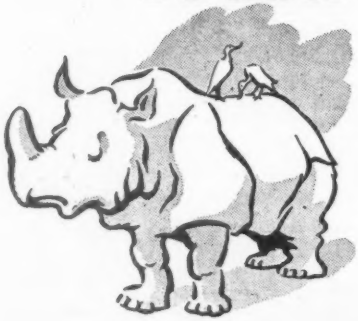

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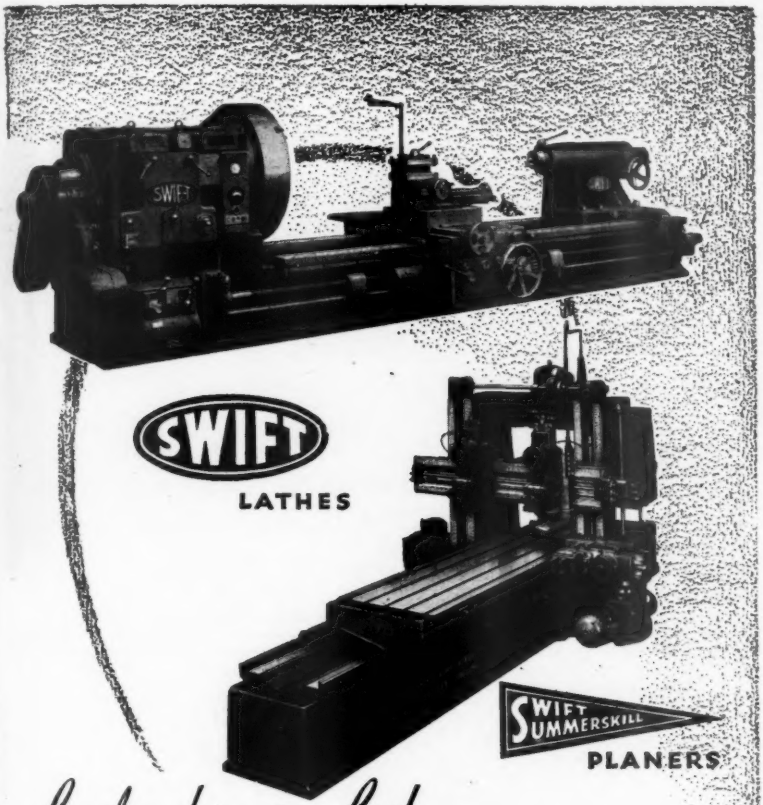

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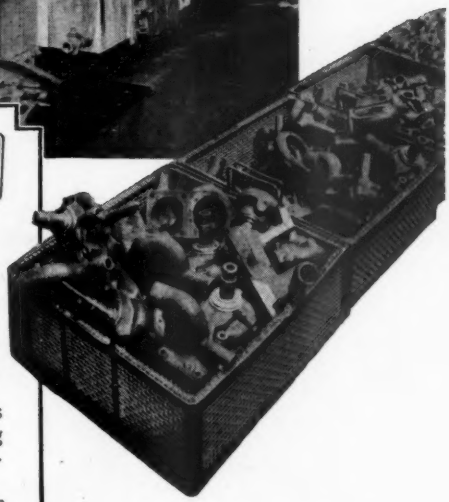

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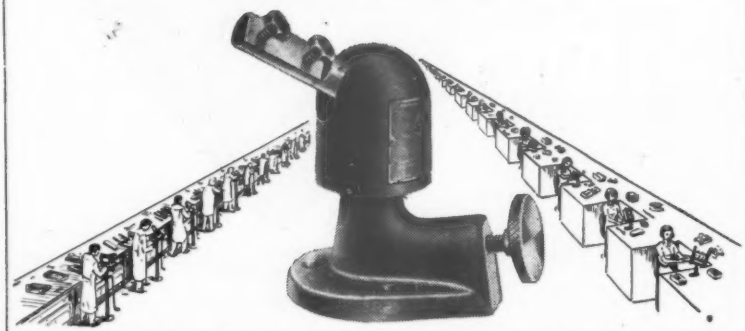

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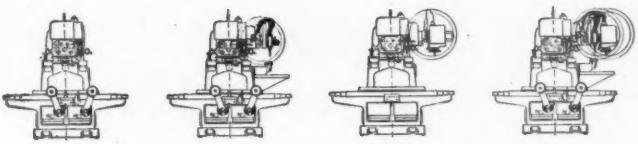

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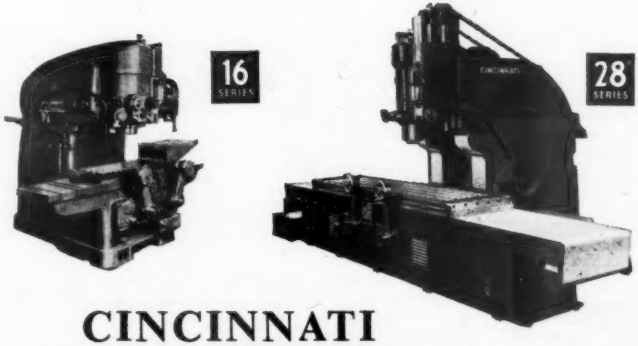

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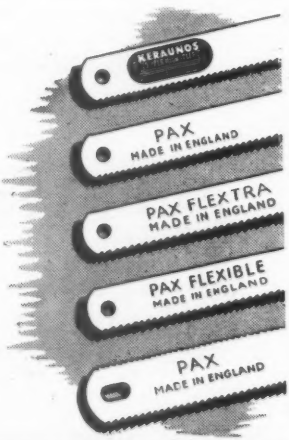

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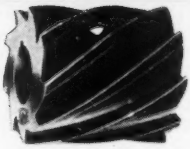

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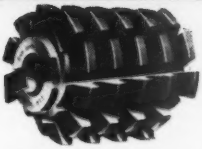

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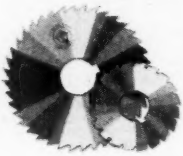

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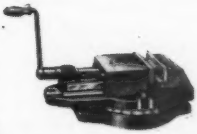

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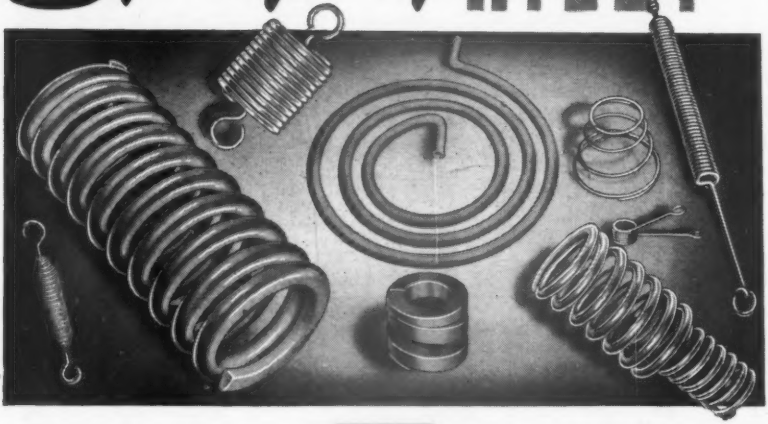

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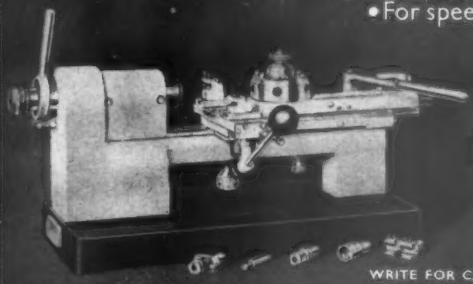

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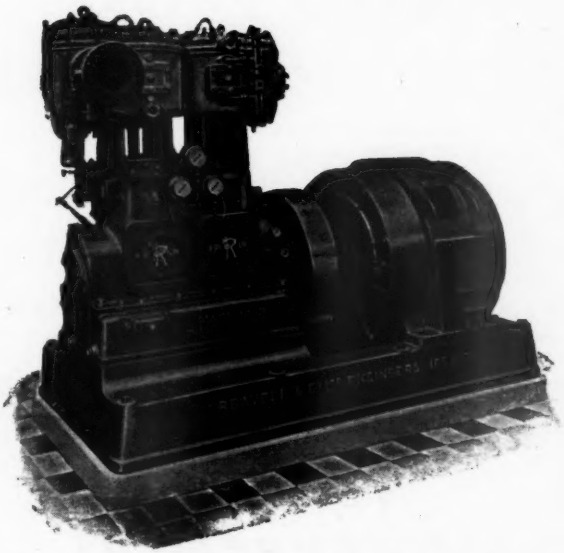

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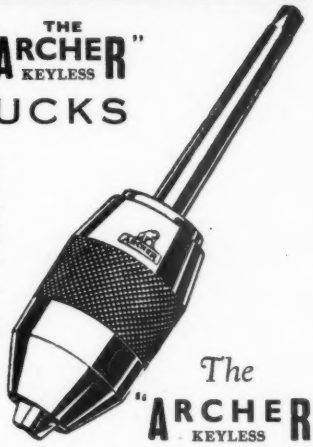

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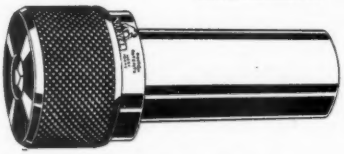

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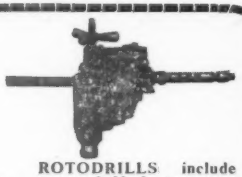

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